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THESIS

AN ANALYSIS OF ROTARY WING OPERATIONS IN URBAN COMBAT USING THE JCATS COMBAT MODEL

by

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September 2001

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The trend of the world's population toward urban areas in the littoral region and increased likelihood of urban conflict has shifted the focus of the military to operations in the urban environment. There is interest within the DoD to evaluate the ability of U. S. forces to operate in the urban environment. In recent years, the Marine Corps has spent considerable time and effort conducting analysis on and development of urban warfare Tactics, Techniques and Procedures (TTPs). There is a need to refine and improve rotary wing operations in this setting.

This thesis modeled and conducted analysis on rotary wing (RW) operations in urban combat using the Joint Conflict and Tactical Simulation (JCATS) combat model. Focus was given to aircraft survivability to evaluate varying tactics and techniques to aid in development of Marine Corps RW TTPs. Thesis objectives were to evaluate rotary wing (RW) survivability in urban combat, determine the major factors impacting on RW survivability, give insight into the development of Marine Corps urban RW TTPs, and to evaluate JCATS as an urban combat modeling tool.

A fractional factorial design was used to vary tactical factors and evaluate their effects. Measures of Effectiveness (MOEs) for evaluation of these effects included Blue RW kills and Blue RW detections.

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AN ANALYSIS OF ROTARY WING OPERATIONS IN URBAN COMBAT USING THE JCATS COMBAT MODEL

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ABSTRACT

The trend of the world's population toward urban areas in the littoral region and increased likelihood of urban conflict has shifted the focus of the military to operations in the urban environment. There is interest within the DoD to evaluate the ability of U. S. forces to operate in the urban environment. In recent years, the Marine Corps has spent considerable time and effort conducting analysis on and development of urban warfare Tactics, Techniques and Procedures (TTPs). There is a need to refine and improve rotary wing operations in this setting.

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TABLE OF CONTENTS

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LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS

AAA	Anti-Aircraft Artillery
ACE	Aviation Combat Element
AGL	Above Ground Level
CAS	Close Air Support
CE	Command Element
CSSE	Combat Service Support Element
FMFM	Fleet Marine Force Manual
GCE	Ground Combat Element
JCATS	Joint Conflict and Tactical Simulation
LAV	Light Armored Vehicle
LZ	Landing Zone
MAGTF	Marine Air Ground Task Force
MANPADS	Man Portable Air Defense Systems
MCWL	Marine Corps Warfighting Lab
MCWP	Marine Corps Warfighting Publication
MEB	Marine Expeditionary Brigade
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
METT-TSL	Mission, Enemy, Terrain & Weather, Troops & Fire Support - Time, Space and Logistics
MOOTW	Military Operations Other Than War
MOUT	Military Operations on Urban Terrain

NCA	National Command Authority
NGF	Naval Gunfire
OMFTS	Operational Maneuver from the Sea
RPG	Rocket-Propelled Grenade
SEAD	Suppression of Enemy Air Defenses
TRAP	Tactical Recovery of Aircraft and Personnel
TTP	Tactics, Techniques and Procedures

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EXECUTIVE SUMMARY

The rise in importance of urban operations has spurred DoD interest to evaluate the ability of U. S. forces to operate in the urban environment, develop new tactics and doctrine, and to develop models and simulations that accurately depict urban operations. This thesis models and conducts analysis on rotary wing (RW) operations in urban combat. Focus is given to aircraft survivability to evaluate varying tactics to aid in development of Marine Corps RW Tactics, Techniques and Procedures (TTPs).

The thesis objectives include:

- Evaluate rotary wing survivability in an urban environment
- Determine major factors that impact on survivability
- Evaluate effect of urban SEAD on RW survivability
- Give insight into development of doctrine and TTPs for urban RW operations
- Evaluate JCATS as an urban operations modeling tool

For this thesis we use the Joint Conflict and Tactical Simulation (JCATS) combat model to run all simulations. Used throughout the DoD and other U.S. government agencies, JCATS was developed by Lawrence Livermore National Laboratory for combat and conflict training, exercises, analysis, experiments and rehearsals. It evolved from a merger of the Joint Tactical Simulation (JTS) and the Joint Conflict Model (JCM). JCATS is a multi-sided, high resolution, entity level, combat simulation model.

Focus is placed on determining and evaluating the factors that have the greatest influence on survivability. Urban rotary wing operations are very complex and involve many variables, situations and factors. Emphasis is placed on a combat scenario that simulates company-sized tactical insert of troops to an urban objective (Urban Penetration). The scenario also involves assumptions about the forces involved. These include, but are not limited to, types of urban terrain, enemy and friendly force structure, tactics, capabilities, and intelligence. The analysis includes the use of quantitative MOEs that assess overall survivability of rotary wing aircraft in an urban setting. Consideration

is given to the validity of the combat model and its depiction of rotary wing operations. Qualitative analysis is made to conduct a face validation of the simulation output. A 2^{6-2} fractional factorial design is used to conduct analysis of simulation results.

For Assault aircraft, Altitude and SEAD prove to be the significant factors for survival. Altitude, number of routes, number of LZs and SEAD presence influence detection rate of these aircraft. Detection rates can be lowered significantly if profiles are flown at low altitude, with multiple avenues of approach and LZs as well as the use of SEAD. Escort aircraft fared the best when in low altitude profiles. Though not statistically significant at our alpha level, SEAD did improve survivability. Of note, the number of routes and LZs do not influence aircraft kill rates in this scenario. LZ results may be reflective of the small objective area used in this scenario.

Given the tactical circumstances of this scenario, rotary wing aircraft are survivable in an urban environment. The GCE no-go criteria (less than seven CH-46E equivalents in zone) was never reached. Of the 180 total runs made, seven assault kills (the highest number of assault aircraft killed) was achieved three times. The highest number of assault aircraft killed at low altitude was four. Escort aircraft endure a higher casualty rate, but this is to be expected given the nature of their mission. If proper tactical procedures are followed, RW aircraft will survive in urban combat.

The qualitative results looking at simulation realism are encouraging. From the standpoint of RW aircraft, the model outputs appear to be realistic. When Altitude and Enemy levels were increased to their higher levels, resulting casualty and detection rates were understandably higher. The acquisitions and kill shots of all weapon systems are realistic and within the capabilities of the system being modeled. Overall, the output for RW urban operations appears to be realistic.

I. INTRODUCTION

A. INCREASING EMPHASIS ON URBAN OPERATIONS

In recent years urban warfare has become an extremely important issue. The likelihood that military forces will fight in cities is increasing. There are many reasons for this trend: continued urbanization and population growth; a new, post-Cold War U.S. focus on support and stability operations; and a number of political and technological incentives for U.S. adversaries to resort to urban warfare [Ref 1: p. 1]. Increasing global urbanization is a predominant post-World War II trend. In 1920 the United Kingdom was the only nation with more than 50 percent of its population in cities and towns of more than 20,000. By 1960, however, one in every four people lived in urban areas worldwide. Ten years later, 12 percent of the world lived in cities with populations over five hundred thousand. The trend continues, as the global population will likely exceed seven billion by 2010, an increase of 25 percent over 1996, with the greatest increase occurring in developing countries [Ref 2: p.3].

People in developing countries seeking an improved quality of life will migrate increasingly to urban areas. Urbanization and population growth will seriously strain fragile societies and weaken infrastructures in some developing states. In crowded urban areas, the negative impact of man-made and natural disasters could be magnified exponentially. Any or all of these conditions could foster political radicalization of populations, and this radicalization in conjunction with increased urban terrain in 2010, especially in developing countries, will increase the probability of urban conflict [Ref 2: p. 4].

The United States Marine Corps (USMC) Fleet Marine Force Manual (FMFM) 1-2, *The Role of the Marine Corps in National Defense*, states, "The increasingly probable terrain for political reinforcement tasks under unanticipated, time-sensitive circumstances is urban." [Ref 3: 3-13] The justification for this resides with the fact that not only is the trend of world population moving towards large urban areas, but also these areas are occurring in littoral regions. Of note, 60 percent of politically significant urban areas (those with political or economic activity that have warranted establishment of a

U.S. embassy, legation or other government agency) outside allied or former Warsaw Pact territory are located within 25 miles of a coastline; 75 percent are within 150 miles of the sea; 87 percent within 300 miles; 95 percent within 600 miles; and all within 800 miles [Ref 4: 1-1].

Along with these facts, there may be advantageous incentives for U.S. adversaries to fight in cities. As a recent RAND study states, many potential adversaries believe that the American public has an antiseptic view of war, with an unrealistic expectation that it can be waged with minimal casualties. The recent victory of Operation Allied Force in Serbia was achieved without a single combat casualty. Adversaries believe that the U.S. public's misplaced confidence in high-technology weapons increase our sensitivity to casualties. This sensitivity is viewed as a liability, because the infliction of a sufficient number of American casualties has a potential to undermine domestic political support of military action [Ref 1: p. 2].

B. THESIS PURPOSE

The rise in importance of urban operations has spurred an interest within the DoD in evaluation of U.S. forces ability to operate in this setting. This has caused the development of new tactics and doctrine and the creation of models and simulations that accurately depict urban operations. The Applied Physics Laboratory (APL) at Johns Hopkins University has recently held working groups discussing urban operations and simulation. My thesis tour was spent at APL researching several aspects of urban operations. One area that needed to be addressed was Marine Corps assault support operations. This thesis will model and conduct analysis on rotary wing (RW) operations in urban combat. Focus will be given to aircraft survivability to evaluate varying tactics to aid in development of Marine Corps RW Tactics, Techniques and Procedures (TTPs).

C. URBAN OPERATIONS

1. Urban Combat

Marine Corps Warfighting Publication (MCWP) 3-35.3, *Military Operations on Urbanized Terrain*, defines MOUT as "*all military actions planned and conducted on a topographical complex and its adjacent terrain where manmade construction is the*

dominant feature. It includes combat in cities, which is that portion of MOUT involving house-to-house and street-by-street fighting in towns and cities." [Ref 4: p. 1-2]

The urban environment differs greatly from that of an open battlefield. It is a far more complex network of buildings, roads and subterranean features. The battlespace is divided into four basic levels: buildings, street, subterranean and air. Of these levels there are seven common characteristics: population density, urban area size, street patterns, structural density, urban patterns, building construction and features of special consideration. Most operations will include fighting on all levels simultaneously. Fighting in the city increases the difficulty of operations being conducted by an offensive force. Distances become compressed, making it more difficult to engage with standoff weapon systems and increasing the likelihood of fratricide or collateral damage. Combat operations also require a vast amount of resource expenditure to include personnel, ammunition and supplies.

Combat operations in an urban environment are conducted in five phases: preparation, isolation, penetration, exploitation and consolidation/transition. They are infantry-intensive and require precise coordination of combined arms. There is not necessarily a distinct transition point between phases. One phase may instead fade into the next [Ref 5: p.7].

2. U. S. Marine Corps Structure

The Marine Corps organizes its operational forces as Marine Air Ground Task Forces (MAGTF) for the purpose of providing a task-organized, self-sustaining, multipurpose expeditionary force capable of responding to a wide range of missions. The MAGTF is a balanced, air-ground combined arms mix of forces under a single commander. It is the Marine Corps' principal organization for all missions across the range of military operations. All MAGTF's are task-organized and vary in size and capability according to the assigned mission.

All MAGTF's are composed of four core elements: a command element (CE), a ground combat element (GCE), an aviation combat element (ACE) and a combat service support element (CSSE). MAGTF's are categorized into three types: a Marine Expeditionary Force (MEF) (division/wing), a Marine Expeditionary Brigade (MEB)

(regiment/group) and a Marine Expeditionary Unit (MEU) (battalion/squadron). The size of these categories can vary, but are generally of the size indicated in parentheses. The scenario for this thesis will involve the use of an ACE from a Marine Expeditionary Unit.

3. Assault Support Operations in Urban Terrain

Typical missions associated with MOUT range from Military Operations Other Than War (MOOTW) such as non-combatant evacuation operations (NEO) and humanitarian aid to sustained combat operations. The ACE of the MAGTF will be expected to support the ground force scheme of maneuver throughout the operation. Assault support missions are those that use aircraft to provide tactical mobility and logistic support for the MAGTF, the movement of high priority cargo and personnel within immediate area of operations, in-flight refueling, and evacuation of personnel and cargo [Ref 6: p. C-3].

In its support of the GCE, the ACE may be called upon to perform missions such as tactical insertion of ground forces and cargo, direct action, combat resupply and tactical recovery of aircraft and personnel (TRAP). In the end, the ground tactical plan will drive the assault support mission.

D. JCATS

For this thesis we used the Joint Conflict and Tactical Simulation (JCATS) combat model to run all simulations. Used throughout the DoD and other U.S. government agencies, JCATS was developed by Lawrence Livermore National Laboratory for combat and conflict training, exercises, analysis, experiments and rehearsals. It evolved from a merger of the Joint Tactical Simulation (JTS) and the Joint Conflict Model (JCM). JCATS is a multi-sided, high resolution, entity level, combat simulation model. JCATS can model strategic through tactical levels across the broad spectrum of war, from Joint Task Force head-to-head engagements to individual conflicts in Operations Other Than War (OOTW) [Ref 7: p. 5].

The high-resolution nature of JCATS allows the user or analyst to control the inputs and actions for individual systems in a scenario. The model also allows forces to be aggregated into units or combat organizations for easier control. The user directs

movement and activities of the systems and units under his control through the model environment with pre-planned or real-time routes. The environment for the model consists of a terrain file that can be created from elevation data obtained from the National Imagery and Mapping Agency in the form of digital terrain elevation data (DTED) [Ref 7: p. 6].

Some important capabilities of JCATS include:

- Amphibious landing and submarine play
- Four levels of acquisition (capable of airborne IFF)
- Three dimensional solid buildings modeled as objects on the terrain
- Movement and conflict in and around buildings
- Cover and concealment near buildings
- Mount/dismount of airplanes/helicopters
- Night operations
- Precision guided weapons with laser spotting
- Subterranean features

These JCATS features, paired with appropriate technical data and tactical inputs, can be combined to simulate operations and tactics of a given force.

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II. SCENARIO DEVELOPMENT

A. BACKGROUND

Much of the analysis on urban operations within the Marine Corps is conducted by the Marine Corps Warfighting Lab (MCWL). The MCWL was created in 1995 and tasked with improving current and future Naval expeditionary capabilities. The lab developed an initial three-phase, five-year experimentation plan beginning in 1996. The first phase, *Hunter Warrior*, examined operations on dispersed, non-contiguous battlespace. The second phase, *Urban Warrior*, examined TTPs and emerging technologies that might be used in urban environments. In the third phase, *Capable Warrior*, experimentation was focused on expeditionary operations in the littorals and examined some of the challenges associated with Operational Maneuver from the Sea (OMFTS) [Ref 8: p. 2].

As part of *Capable Warrior*, a battalion level experiment was conducted in February of 2001 called Project Metropolis (ProMet) at the former George Air Force Base in Victorville, California. Experiment focus areas included tactics, training, combat service support, casualty collection treatment, and evacuation and rotary wing operations. Rotary wing experimentation objectives were to assess and evaluate urban Close Air Support (CAS) TTPs, aircrew target identification, urban suppression of enemy air defense (SEAD) TTPs, effectiveness of current tactics against man-portable air defense systems (MANPADS) and survivability of assault support helicopter lifts. As a result of this exercise a considerable amount of information was gained regarding rotary wing operations, but due to weather cancellations the assault support infantry company lifts were not conducted. The scenario developed for this thesis will try to give insight into the questions of rotary wing assault aircraft survivability by analyzing the factors that influence it [Ref 9: p. 46].

B. U. S. MARINE CORPS ROTARY WING AIRCRAFT

This thesis will involve the modeling and simulation of Marine Corps rotary wing aircraft involved in assault support operations. The following paragraphs give a summary of the four aircraft used in this simulation, their roles and missions.

1. CH-53E Super Stallion

The CH-53E, the Marine Corps' heavy lift helicopter (Figure 1), provides assault helicopter transport of heavy weapons, equipment, personnel and supplies in the initial waves of amphibious operations and subsequent operations ashore.

Figure 1. CH-53E Super Stallion inserts NATO ground forces into urban LZ

Some of the main missions for the CH-53E include providing combat assault transport of heavy weapons, equipment and troops, TRAP for downed aircrew and equipment, providing assault support for evacuation operations and other maritime special operations and providing support for mobile forward arming and refueling points (FARPs).

2. CH-46E Sea Knight

The Marine Corps' medium lift helicopter, the CH-46E (Figure 2) provides assault transport of combat troops in the initial assault waves and follow-on stages of amphibious operations and subsequent operations ashore.

Figure 2. CH-46E Sea Knight conducting fastrope operations in urban setting

The major tasks for the CH-46E are to provide combat assault troop transport, conduct assault support evacuation operations and other maritime special operations, and provide support for mobile FARPs.

3. AH-1W Cobra

The AH-1W (Figure 3) provides attack helicopter fire support and fire support coordination during amphibious operations and subsequent operations ashore. The primary tasks for attack helicopters is to provide fire support and security for forward and rear area forces, point-target and anti-armor operations, and anti-helicopter operations; provide armed escort, plus control and coordination for assault operations; controlling/coordinating and providing terminal control for supporting arms, including CAS, artillery and Naval Gunfire (NGF); and conducting armed and visual reconnaissance.

Figure 3. AH-1W Cobra

4. UH-1N Huey

The UH-1N (Figure 4) provides combat utility helicopter support and fire support coordination during amphibious operations and subsequent operations ashore. The primary tasks of the utility missions include providing an airborne command and control platform for the command element, providing armed escort for assault support operations, airborne control and coordination for assault support operations, conducting combat assault and assault support for evacuation operations and other maritime special operations, and controlling, coordinating and providing terminal control for supporting arms.

Figure 4. UH-1N Huey

C. EXPERIMENTAL TACTICS

Urban terrain offsets many of the strengths in the U.S. doctrinal warfighting capabilities. The effectiveness of satellites and reconnaissance assets appear to be severely reduced in the dense clutter and density of urban terrain. Firepower inflicts collateral civilian casualties and crumbles the infrastructure. The rubble in turn prevents rapid maneuver and affords the defender increased protection. Messy and chaotic, urban warfare is far from the long-range precision weapon engagements of Desert Storm. In the city, engagement distances are compressed and identification of friend from foe and non-combatant is inherently difficult [Ref 8: p. 6].

In the urban environment the squad leader often becomes the basic maneuver element and the lowest level battle leader with the ability of independent operations. Emphasis will be given to the squad leader as the tactical decision maker. The MCWL has developed several new tactical concepts for use in the urban battlespace. All are based on the precepts of maneuver warfare and seek to explore the potential utility of dispersed, non-linear operations. The paragraphs below describe the tactical concepts of *Urban Penetration, Urban Thrust* and *Urban Swarm*.

1. Urban Penetration

This tactic involves a force entering the urban battlespace from a safe haven to an objective within the city. It is designed for operations against clearly defined objectives, either enemy or terrain. Focus will be given to quickly maneuver to the objective and establish control in a dispersed and non-contiguous battlefield. The avenues of approach between the safe haven and objective are only controlled during the passage of the force. Upon arrival at the objective area the force must move directly into the attack. After seizing the objective the force must then isolate and defend it. The forces involved in the penetration must have skills necessary to make opposed movement to the objective, attack, seize and conduct then conduct immediate defense.

Attacks will occur on multiple axes of advance by dispersed units. Isolation and defense of the objective will require the ability to protect against enemy forces as well as non-combatants. A withdrawal may be planned, but not required, and could be considered as a transition to a second objective.

2. Urban Thrust

This is a tactical concept that focuses an attack on the enemy on a narrow axis of advance. As the attack occurs the axis of advance is defended to refuse the flank to the enemy. This is accomplished by forces, sensors and barriers. It can be conducted along multiple axes that are mutually supporting and on an oblique axis to the street to avoid exposure. Periodic shifts in advance direction can be used to confuse the enemy and avoid patterns. The intent is to avoid linear attacks, deceiving the enemy and disguising the true nature of the attack.

3. Urban Swarm

The urban swarm tactic involves numerous fireteam and squad-sized units operating in a dispersed, non-contiguous manner. The units patrol their assigned areas and are continuously prepared to rapidly respond to calls for assistance by other patrol teams. Responses are made by either the closest unit or by those units given direction by higher authority. The key to this tactic is speed and flexibility. Implicit in this concept is the need for junior leaders to take on greater levels of responsibility and command.

D. URBAN ROTARY WING OPERATIONS

The MAGTF may be tasked with conducting numerous urban missions. These may include offensive/defensive combat operations, non-combatant evacuation operations, hostage recovery, tactical recovery of aircraft and personnel, airfield seizure, humanitarian assistance or show of force. Ultimately the ground tactical plan will drive the assault support mission. For offensive combat operations, mission planning will begin and be focused on the METT-TSL factors. Decisions will be made to determine routing, landing zones (LZ), altitude, airspeeds and other flight profile factors. For large troop lifts (company size or larger) the size of the flight will also impact on the tactics that are chosen. Appendix A shows the Assault Support Decision Matrix that can be used for selection/rejection of a course of action (COA) for an assault into urban terrain. The paragraphs below briefly discuss the major planning issues associated with assault support missions.

1. Routing

The threat is the biggest driving force in route selection. Routing is selected to ensure the greatest element of surprise, ease of navigation, and avoidance of (or cover from) possible threat locations. METT-TSL dependent, tactical dispersion of the flight may require small flight elements vice a single large flight. This may be coordinated through time, space and altitude deconfliction to a single LZ or to multiple LZs.

2. Altitude and Airspeed

Like route selection, threat is the driving factor to altitude and airspeed requirements. Automatic weapons, light AAA and MANPADS are usually the primary threat in an urban environment. The general rule is to maintain airspeeds greater than 60 knots and altitudes just above the height of obstacles. Higher airspeeds allow for the minimization of exposure time. Terrain flight techniques will consist of low level and contour techniques. Higher airspeeds and lower altitudes result in lower reaction time and reduced situational awareness (SA). Ease of navigation, SA and reaction time must all be weighed against the mission and threat. If the threat is primarily small arms and RPGs an altitude of 1500 feet AGL is preferred.

3. Landing Zones

The mission and the GCE requirements will primarily dictate LZ choice. Consideration will be given to ease of recognition, ambush potential and distance from objective. Stadiums and rooftops are potential zones, but steeper approaches, slower airspeeds, manmade obstacles, and increased exposure time must be weighed against landing zone benefits. Initial Terminal Guidance (ITG) provides terminal control for helicopters in and around LZs. Whenever possible, consideration should be given to provide some sort of ITG whether it be IR strobes, chemlights, laser or some other technique.

E. THESIS OBJECTIVES

This thesis contributes towards the development of Marine Corps urban rotary wing TTPs by modeling and analysis of these operations. The thesis objectives include:

- Evaluate rotary wing survivability in an urban environment.
- Determine major factors that impact on survivability.
- Evaluate effect of urban SEAD on RW survivability.
- Give insight into development of doctrine and TTPs for urban RW operations.
- Evaluate JCATS as an urban operations modeling tool.

F. THESIS SCOPE

This thesis develops a scenario to model rotary wing operations in an urban environment using the JCATS combat model. Focus is placed on determining and evaluating the factors that have the greatest influence on survivability. Urban rotary wing operations are very complex and involve many variables, situations and factors. Emphasis is placed on a combat scenario that simulates company-size tactical insert of troops to an urban objective (Urban Penetration). The scenario also involves assumptions about the forces involved. These include, but are not limited to, types of urban terrain, enemy and friendly force structure, tactics, capabilities and intelligence. Full scenario development and assumptions are discussed in Chapter III. The analysis includes the use of quantitative MOEs that assess overall survivability of rotary wing aircraft in an urban setting, which are discussed in Chapter IV.

Consideration has been given to the validity of the combat model and its depiction of rotary wing operations. Qualitative analysis will be made to conduct a face validation of the simulation output [Ref 10: p. 34]. Chapter IV includes a discussion of validation requirements involved with a combat model; however, a full validation of the JCATS combat model is not within the scope of this thesis.

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III. MODEL DISCUSSION

A. SCENARIO

The combat scenario for this thesis will involve an infantry company conducting an Urban Penetration into a hostile city in order to seize and defend the objective until follow-on forces arrive. The insertion will be completed by MAGTF RW assets. This scenario is typical of a mission that a MEU would be called upon to execute. The scenario was generated by the author, but is similar to the urban penetration missions executed in the ProMet exercise mentioned in Chapter II. Details for the scenario are described below.

1. Situation

Recent economic and political instability in the country of Red has led to social uprising and creation of Red rebel forces known as the Red Liberation Front (RLF). A recent rise in tensions led to the seizure of the U. S. Embassy Compound in the city of Jabal by approximately 30 well-armed RLF members.

Since the tensions have been rising for some time, the 29th MEU (SOC) was offloaded in the neighboring county of Orange to conduct training and respond to any potential hostilities. The NCA has tasked the MEU with seizing the Embassy Compound and defending until follow-on forces arrive and stabilize the situation.

2. U. S. Forces

The U. S. forces for this scenario are represented as the Blue side in the simulation. The Blue force includes assets that are typical of a forward-deployed MEU(SOC). The forces utilized in the simulation are rotary wing composite squadron, a Light Armored Reconnaissance (LAR) company and one infantry company (Alpha). The composite squadron consists of 12 CH-46Es, four CH-53Es, four AH-1Ws and two UH-1Ns. The LAR company consists of 12 LAVs, and Alpha Company is comprised of 110 Marines. Alpha Company will be deployed aboard the RW aircraft. In addition to these forces, a Marine scout/sniper team will be used, consisting of four Marines.

3. Red Forces

The RLF forces are represented by the Red Side in the simulation. The forces involved in the taking of the U. S. Embassy are comprised of 54 rebels. The RLF typically operate in squad-sized elements. They are armed with former Soviet weapons including AK-74s, RPG-16s, AT-4s, SA-14s, and SA-16s. The RPG-16 and AT-4 are anti-tank/armor weapons, but can and have been used against RW aircraft. The SA-14 is a second generation Infrared (IR) MANPAD. The SA-16 is a third generation IR MANPAD with greater range and capability than the SA-14. Both of these weapons are primary threats to RW aircraft. Rebel platoons are composed of three of these squads. Each squad consists of nine soldiers, for a total of 27 rebels per platoon. A single platoon is located at the Embassy Compound.

In addition to the forces occupying the embassy compound, there are some rebel factions operating in squad-sized elements in the surrounding blocks of the city. There is also one ZPU-4 Anti-Aircraft Artillery (AAA) piece (14.5mm) located on a rooftop approximately 600 meters to the east of the objective.

4. Scheme of Maneuver

The countries of Orange and Red can be seen in Figure 5. The Blue Forces are located at the airfield in the western sector of the map in the Country of Orange. At H-Hour, the LAR company will proceed enroute to the city of Jabal and conduct a feint on the eastern side of the city; this will draw forces away from the western side of the city where Alpha Company will be inserted by helicopter. The helicopter lift consists of eight CH-46Es and four CH-53Es. Escort will be provided by four AH-1Ws, and a single UH-1N providing command and control (C2). Figure 5 highlights the objective area and outlines the aircraft routing into the objective.

The embassy compound is located in the western sector of the city of Jabal. Three LZs have been identified for use in the assault; LZs Crow, Eagle and Hawk. The compound itself consists of five buildings, all of which are two and three stories. Alpha Company will attack and seize the compound. Once a defensive perimeter has been established, the LAR company will proceed to the objective, linkup with Alpha

Company, and defend the Embassy until follow-on forces arrive and stabilize the situation.

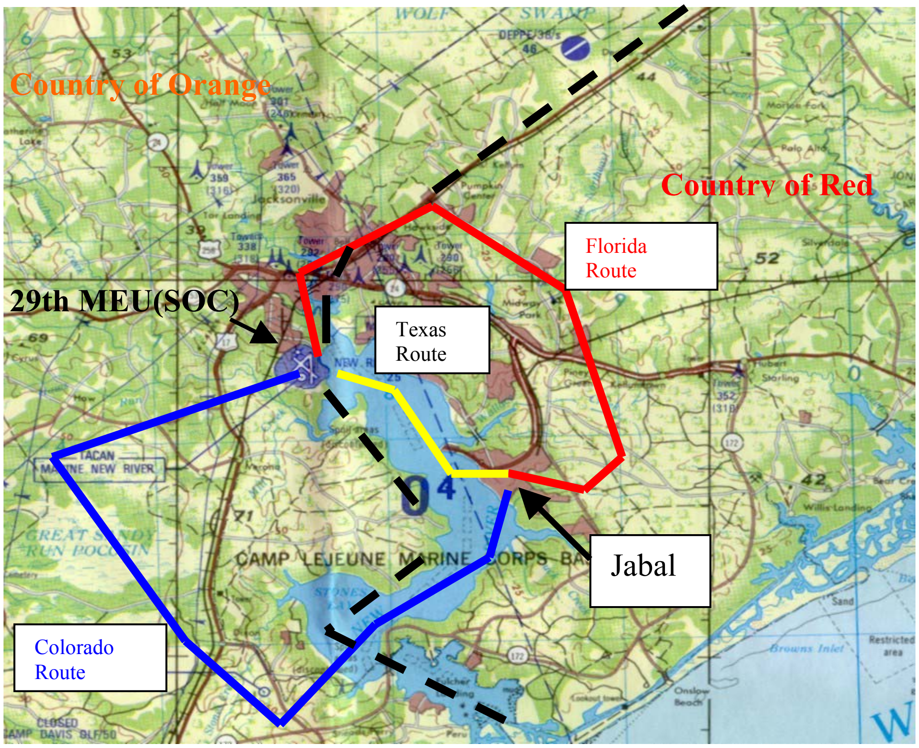

Figure 5. Overview map of Objective Area

A few steps were taken in order to simplify the simulation. We were not concerned with modeling the mechanized forces route of travel, so in order to shorten the simulation, the LAR company was initially positioned at the western side of Jabal at the sight of their feint. Since there was no threat enroute to their objective, this has no effect on the overall results of the simulation. Helicopter lifts commenced at the beginning of the simulation. Finally, the ground scheme of maneuver was played out for 15 minutes after the initial insertion of troops.

Figures 6 and 7 show detail of the objective area. Figure 6 outlines the overall scheme of maneuver for the simulation scenario. Figure 7 displays the embassy compound and adjacent LZs, and is a graphic from the JCATS simulation display. Figure 7 is a blow-up of the western sector of the objective area shown as the boxed region in Figure 6.

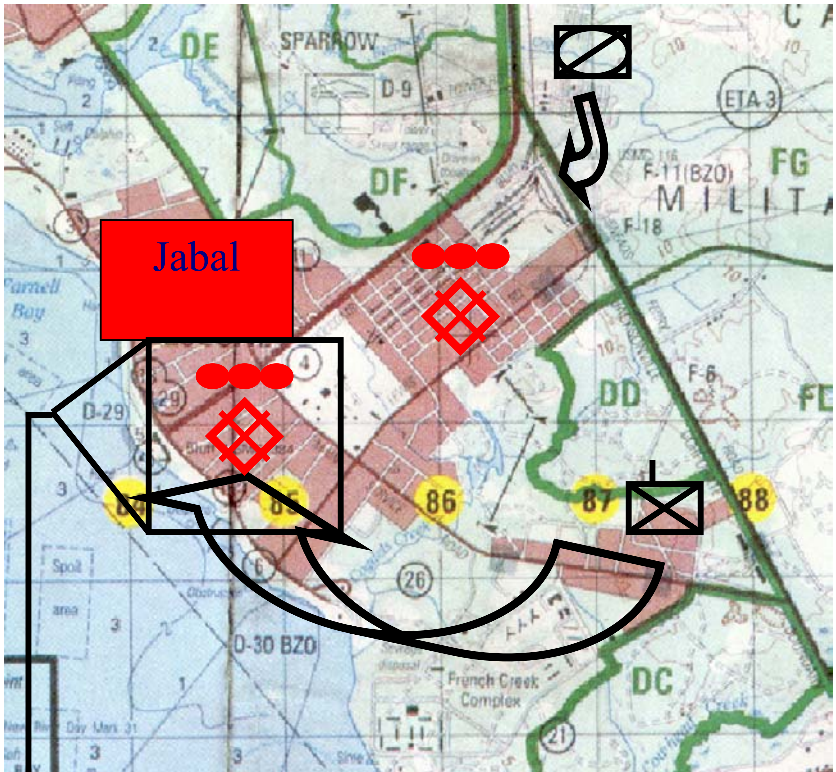

Figure 6. Objective Area

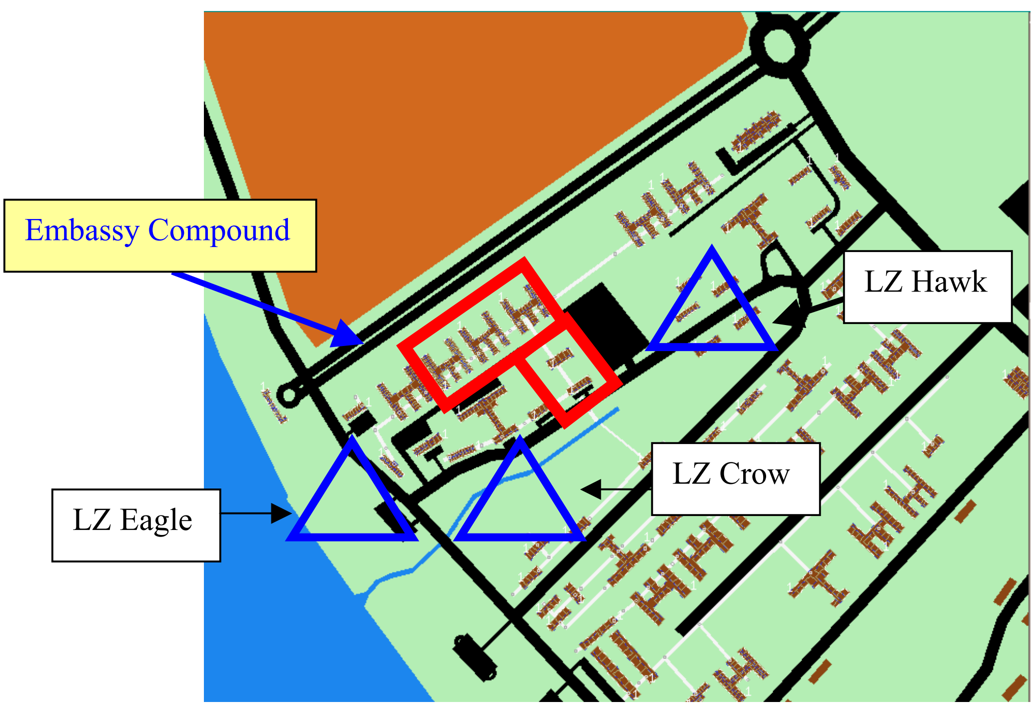

Figure 7. Objective Area LZs

B. FACTORS AFFECTING ROTARY WING SURVIVABILITY

The major factors that influence an assault support mission in an urban environment were developed and further defined for purposes of analysis of the simulation. The factors discussed are not an exhaustive list and the author realizes that others could be developed that can contribute to RW survivability. The factors described below are the major considerations involved with mission planning of RW operations and can be modeled and analyzed within the scope of this thesis. A total of eleven factors were developed, though some are fixed at an assumed level for reasons described below.

1. Urban Terrain Type

Urban areas can range from a small strip of buildings to major metropolitan cities. Size, street patterns, and building features will impact on a forces ability to operate in this setting. Urban areas are generally described by seven common characteristics that effect military operations: population density, urban area size, street patterns, structure density, urban patterns, building construction and features of special consideration.

The predominant urban terrain for this simulation is low-rise building structures, typically three stories in height. Construction is wood frame and masonry-type. The streets are planned, irregular pattern with widths that vary from ten to twenty meters in width. The urban pattern can best be described as a segmented pie structure extending outward from the main city center near the embassy. Population is estimated at approximately 30,000. These features will remain constant throughout, as creating terrain files is quite labor intensive and experimenting in different urban types is beyond the scope of this thesis.

2. Mission Profile

There are numerous mission profiles that could possibly be flown in an urban environment, from RW CAS to Humanitarian Relief resupply missions. The profile will determine the amount of time spent over the city, which will have direct correlation to the aircraft's survivability. For the purposes of this thesis, the mission profile will only include a RW assault troop insert in support of an Urban Penetration operation.

3. Time of Day

Normally the Marine Corps will conduct combat operations during hours of darkness since our ability to operate at night far exceeds the capability of any of our potential adversaries. Since this is an initial study however, we have held our missions to only be flown during daylight hours. Future research could delve into JCATS night simulation features and conduct further analysis of night operations.

4. Aircraft Routing

When operating in an urban setting, consideration must be given to the size of the flight since larger formations require longer periods of time in the objective area, slower approaches into landing zones, larger LZs, and most likely the need for use of holding areas. We are interested in the effect of using multiple avenues of approach into an objective area and how it will influence helicopter survivability. This simulation utilizes one or three routes for the assault aircraft.

5. Landing Zones

The use of a single LZ into an objective area when inserting a large force usually requires multiple waves of aircraft, longer periods of time over hostile territory and allows the enemy to concentrate his forces on a single objective. The use of multiple LZs in the objective area will be analyzed to determine its effectiveness. Like routing, we will utilize one or three LZs.

6. Altitude

Altitude doctrine for urban operations is very well defined and has been developed from combat experience. For the threat defined in our scenario, assault support aircraft would fly at altitudes of 200 feet and below. For both analyzing differences in altitude and determining simulation output validation, altitudes for the scenario will be run at 50 feet above obstacles and at 1500 feet above obstacles.

7. Rotary Wing Escort

There are two forms of rotary wing escort for assault support operations: attached and detached. Attached escort requires that escort aircraft fly with the assault flight into the objective area to provide fire support and protection from possible threats. Detached escort involves RW escort assets ingressing via separate routing and being placed in

mutually supporting areas based on threat and response time. With larger flights, multiple routes and limited escort assets, detached escort may be an option that is taken. Escort options for the scenario will be run with attached or detached escort.

8. Urban SEAD

Suppression of enemy air defenses (SEAD) is defined as activities that neutralize, destroy or temporarily degrade enemy air defenses in a specific area by physical attack and/or electronic attack [Ref 11: p. 7-1]. The proliferation of MANPADS poses the greatest threat to aircraft in the urban environment. SEAD can be accomplished by many platforms to include fixed wing assets, RW aircraft and GCE elements. For the purposes of this thesis, SEAD will refer to the use of GCE recon scout/sniper teams located on rooftops near insert sites to provide cover for landing assault aircraft. Normally they will be inserted several days to several hours prior to the assault, but for the ease of simulation they will be placed at covered positions at the beginning of the simulation. They will be either present or not present to study their contribution to RW survivability.

9. Enemy Tactics/Training

The training level and ability of an enemy will affect the tactics that are employed. A highly trained force will wait for the best opportunity to engage based on unit objectives. A poorly trained enemy is unpredictable and will engage aircraft at every opportunity regardless of the unit's objective. Often times this unpredictability will make the enemy more dangerous and harder to locate. This scenario will assume an average training level of Red forces since simulating training levels can be significantly difficult.

10. Enemy Location/Intelligence

Correct intelligence on enemy location, size, composition, etc are key factors that drive mission planning and execution. Accurate intelligence on adversaries is critical to mission accomplishment, but often times information is not known or is inaccurate. This has a potential to negatively impact operations and can lead to increased casualties. For the purposes of this thesis, intelligence will refer to the accuracy of known enemy locations and composition. This will be assumed at a fixed level for this simulation. Intelligence information on enemy forces will be considered typical. Accurate

information will be 'known' about the force at the embassy, but threats on the city streets outside the embassy will be 'unknown'.

11. Enemy Force Size

The size of the enemy force will obviously influence the size of the attacking force. Traditionally, the attacker desires a minimum 3:1 force ratio. Due to poor intelligence or unexpected reinforcement capability, this may not always occur. This simulation will use both a 2:1 and 3:1 force ratio. This will be useful in determining simulation output validity. This will be accomplished by fixing the friendly force level at a single company and varying the enemy force level between one and two platoons (a total of 27 and 54 soldiers respectively).

C. JCATS MODEL PARAMETERS AND CHARACTERISTICS

Every JCATS scenario has a characteristics and a parameters file associated with it. The characteristics file contains all the data that is associated with each individual entity in the simulation. This includes weapons, munitions and sensor information as well as detailed information about the specifics of the system being modeled, as well as missions and targeting information.

The parameter file contains data regarding variables that affect combat. These include environmental settings, site objects and human factor options. Each is discussed in detail below.

1. Environmental Settings

The environmental options allow for different weather effects to be set for a simulation. These effects include visibility, wind, temperature, humidity and lighting conditions. For this scenario weather conditions are set to a '9 kilometer day', 'clear' and 'good'. These are intended to simulate 9 kilometers of visibility, with clear skies, and good weather conditions. The 'good' weather conditions allows for no degradation of mobility. Set to different levels, this factor can degrade a system's mobility.

2. Site Objects Setting

The Site Object options allow for setting effects of barriers, bridges, buildings and breach/penetration. The barriers option includes data that details distances at which barriers can be perceived. The bridges and buildings options detail information on effects

of munitions on a particular structure, and the breach/penetration option contains data on time to breach/penetrate obstacles.

3. Human Factors Settings

This option contains information for setting a system's behavior under duress. These settings include fatigue and fratricide. Fatigue computes the energy levels for individual dismounted systems based on activity level, combat stress, and training, and restricts activity if a system runs out of energy. The Fratricide option determines the likelihood a system mistakenly targets friendly systems. It includes data such as jumpiness (simulating an entity's nervousness and realized through degradation of weapon and system performance), fatigue, and identification and recognition information for targeting. For simulation speed, ease of processing and data collection, these features were disabled.

D. MODELING ROTARY WING AIRCRAFT IN JCATS

JCATS is an entity level constructive simulation, which defines an entity as a 'system'. Each system is comprised of weapon(s), munition(s) and sensor(s). The weapon information includes data on weapon reliability, set up time, cycle rates and reload time. Munitions information details standard ballistics information for munition type. Sensor options detail type, range, field of view, reliability information and basic characteristics of the sensor.

Each aircraft system is then assigned weapons, munitions and sensors as well as detailed information on aircraft mission, target classification, detectability, size, crew and behavior in the air. Additional parameters are inputted for fuel and cargo capacity, fuel burn rates and, if applicable, whether the systems can transfer fuel (refueling aircraft).

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IV. ANALYSIS METHODOLOGY

A. DEFINITION OF SURVIVABILITY

In order to conduct effective analysis on RW operations we must first define what we mean by survivability. There could be some debate over the definition of survivability. Some would say that the current trend to zero tolerance of casualties would lead to the requirement to operate in an environment unscathed. This is unrealistic and for the purposes of this study, survivability will refer to the ability of rotary wing aircraft to operate effectively in an urban environment. That is to say, the aircraft must be able to accomplish their mission. To do this, enough assault aircraft must survive to be able to insert the ground force in sufficient numbers to enable the GCE to accomplish its mission and seize the objective. This is defined as the GCE go/no-go criteria. For our scenario the go/no-go criteria is 84 Marines in zone. Each CH-46E carries 12 combat loaded Marines, while a CH-53E carries 24. Therefore the go/no-go criteria can be stated as seven CH-46E equivalents in zone.

B. MEASURES OF EFFECTIVENESS

MOEs were developed within the framework of the thesis objectives: evaluate RW survivability in an urban environment, determine which factors impact on survivability and give insight into the development of urban RW TTPs. In order to evaluate RW survivability within the context of this simulation, we broke survivability down into two basic categories: susceptibility and vulnerability. Susceptibility refers to how well the aircraft are able to avoid detection and engagement by enemy forces. Vulnerability refers to how well the aircraft survive engagements. The MOEs are developed in detail below.

1. MOE 1: Blue RW Detections

This MOE will be used to determine the effectiveness of each of the factors on susceptibility. JCATS models acquisitions at four levels: detection, classification, recognition and identification. Detection refers to when something has been spotted within a system's field of regard. The classification level is reached when the general class of something has been determined, that is, a wheeled vehicle, an aircraft, etc.

Recognition occurs when the type of object has been determined, that is, a tank is a T-80, etc. Identification level of acquisition is reached when the side of the system being acquired has been identified. Targets will not be engaged until they have been acquired at the identification level. Therefore we will measure the number of RW identifications made by the Red Force per mission.

2. MOE 2: Blue RW Kills

To determine the effect of each of the factors on vulnerability, we will examine the number of blue RW kills per mission. JCATS defines four types of kills: mobility, firepower, mobility and fire power, and catastrophic. The kills will be separated into assault kills (MOE 2A) and escort kills (MOE 2B). Assault kills represent the number of CH-46E equivalents killed per mission to determine if GCE go/no-go was met. Escort kills represent the number of AH-1W and UH-1N killed per mission and will reflect how well escort aircraft can operate in this setting.

C. FACTORIAL DESIGN

To determine the factors influencing survivability we will use a factorial design. In a two-level factorial design experiment, two levels or settings are selected for each variable or factor. Experimental runs are made with all possible combinations for a full factorial design. These designs are useful because they require a few runs per factor and they can indicate major trends [Ref 12: p. 306]. This scenario includes six of the factors mentioned earlier for evaluating RW survivability; altitude, number of routes, number of LZs, SEAD, type of RW escort and enemy force size. Table 1 displays the levels for each of the design factors.

Design Factor		Level	
Label	Description	-	+
A	Altitude		
B	Number of Routes	1	3
C	Number of LZs	1	3
D	SEAD	Use	Not Use
E	RW Escort	Detached	Attached
F	Enemy Force Size	27 (3:1)	54 (2:1)

Table 1. Levels of each Design Factor in the Experimental Design

In 2^k factorial designs the amount of experimental runs increases geometrically as k increases. For our 2^6 design, a full factorial experiment would require 64 separate treatment runs. However, when k is large enough the desired information can often be obtained by performing only a fraction of the full design [Ref 12: p. 374]. Fractional factorial designs provide a good way to get estimates of main effects and two-way interactions at a fraction of the effort required by a full design [Ref 13: p. 638].

We are primarily concerned with main effects which are defined as the average change in the response due to moving a factor from its "-" level to its "+" level while holding all other factors fixed. However, if two or higher interactions appear to be present, the main effects cannot be readily interpreted as simply the effect of moving from a factor's lower level to its higher level [Ref 13: p. 629]. Therefore, this will

require a resolution IV design. "*A design of resolution IV does not confound main effects and two-factor interactions with each other, but does confound two-factor interactions with other two-factor interactions*." [Ref 12: p. 385] We have assumed that three-factor interactions are negligible, leaving two-factor interactions confounded with each other. Effects of the two-factor interactions can be determined for each of the pairs confounded. A 2^{6-2} design is a Resolution IV design with a 1/4 fraction of the full 2^6 design. Appendix B details the 2^{6-2} design, displaying the factor levels for each of the required 16 treatment runs per replication, as well as the generator and confounding patterns [Ref 12: p. 379-383].

D. ANALYSIS OF VARIANCE (ANOVA)

A multi-factor analysis of variance will be conducted to test whether each factor, or treatment effect, on the response is significant. The model that describes our response variable is the sum of the grand mean (μ), treatment effect i (τ_i) and an error term (ε_{ij}), depicted below:

$$y_{ijk} = \mu + \tau_i + \varepsilon_{ij}$$

where

y_{ijk} = response observation of treatment i, replication j and run k

μ = true mean

τ_i = treatment i effect   i = 1,...,6   j = 1,...,10

ε_{ij} = error term   k = 1,...,16

For our model we have six factors, 16 treatments and 10 replications of each of the 16 treatments [Ref 14: p. 456]. The ANOVA for our model tests six (total number of factors) separate hypotheses; H_o: τ_i = 0, that is, factor i has no effect on the response. The alternative hypothesis being; H_a : $\tau_i \neq$ 0, factor effect i has a significant effect on the response [Ref 14: p. 424].

The ANOVA calculates the mean square for treatment (MSTr) and the mean square for error (MSE). The statistic f = MSTr/MSE is then calculated. When the null hypothesis is true, E(MSTr) = E(MSE) = σ^2, where as when the null hypothesis is false, E(MSTr) > E(MSE) = σ^2. That is, both of the statistics are unbiased estimators of the

common variance when Ho is true, but MSTr overestimates σ^2 when H_o is false [Ref 13: p. 396]. When Ho is true the test statistic *f* has an F distribution. Thus a significance level can be calculated to determine if each factor has a significant affect on the response. (rejection region; $f \geq F_{\alpha,\nu 1,\nu 2}$)

E. MODEL VALIDITY

One of the objectives of this thesis is to conduct a face validation of the simulation output of our scenario. Army Pamphlet 5-11, Verification, Validation and Accreditation of Army Models and Simulations, defines validation as "*...the rigorous and structured process of determining the extent to which an M&S accurately represents the intended real world phenomena from the perspective of the intended use of the M&S*." [Ref 10: p. 30]

There are two components to validation: structural and output. Within each of these two components there are methods by which to conduct the validation. The analysis conducted for this thesis will focus on output validation. Output validation seeks to find the answers to the following questions:

- Does the Model and Simulation (M&S) produce results that are feasible?
- Is the result reasonable relative to the inputs?
- Does a difference in input produce the expected proportional change in the output?

The methods are the means to which validation is measured. For the purpose and scope of this thesis, a face validation will be used to evaluate the model. A face validation is the method of determining if at the surface the model seems reasonable and results are within the realm of possibility. It is conducted by personnel that are knowledgeable or considered subject matter experts about the system(s) being modeled. It is considered a point of departure from which to conduct more thorough validation analysis [Ref 10: p. 35-36].

For our analysis, we will make qualitative assessments of the output generated by the scenario. Focus will be given to RW kills, casualty rates, realism of shots taken and

movement rates of forces. We hope to achieve an overall evaluation of the JCATS model as a tool for modeling urban combat.

F. DATA COLLECTION

JCATS simulation runs generate three files of output data. These data files can then be used by the JCATS Analyst Workstation to generate appropriate files for the data that is desired. The Analyst Workstation converts the original three output data files into useable output and then generates several files and reports. Some of these files include acquisitions, direct fire shots, direct fire effects, direct fire kills, artillery kills and so forth. For the purposes of our analysis three of these files were used: acquisitions, direct fire effects and direct fire kills. The acquisition files contain data on the system being acquired, the system acquiring, level of detection, location and force organization information. The direct fire effects file includes information on each shot taken by each side, type of kill (or miss), target, shooter and range of shot. Finally, the direct fire kills file contains data on target system killed, shooter and total kills of that system type.

These three files were downloaded, imported into Excel, reduced into a usable format and consolidated. The resulting Excel data files were then imported into S-Plus for analysis.

V. RESULTS

A. ANALYSIS PROCEDURE

Ten replications of the 16 treatments (160 total runs) were conducted to generate enough response observations for each MOE to ensure accurate determination of factor effects. The raw results were analyzed using multi-factor ANOVA in S-Plus. The raw results are included in Appendix C. The ANOVA was conducted on all MOE response variables. The results are summarized below. A pre-determined significance level of $\alpha = .05$ was set.

B. MOE 1: BLUE RW DETECTIONS

1. Factor Significance

The ANOVA results from the Blue RW level 4 detections are shown in table 2.

ANOVA
(Response Variable: Blue RW Detections)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Alt	1	138650.6	138650.6	54.1660	0.0000000
Rtes	1	35343.0	35343.0	13.8073	0.0002878
LZs	1	45900.6	45900.6	17.9318	0.0000403
SEAD	1	11323.2	11323.2	4.4236	0.0371606
Escort	1	1677.0	1677.0	0.6552	0.4195928
Enemy.Size	1	309936.0	309936.0	121.0812	0.0000000
Alt:Rtes	1	9579.0	9579.0	3.7422	0.0549887
Alt:LZs	1	10465.2	10465.2	4.0884	0.0450051
Alt:SEAD	1	10080.6	10080.6	3.9381	0.0490771
Alt:Escort	1	12709.2	12709.2	4.9651	0.0273933
Alt:Enemy.Size	1	8614.2	8614.2	3.3653	0.0686200
Rtes:SEAD	1	21.0	21.0	0.0082	0.9279111
Rtes:Enemy.Size	1	6943.2	6943.2	2.7125	0.1017171
Residuals	146	373721.7	2559.7		

Main Effects

	Effects	se
Alt	58.875	8.403
Rtes	-29.725	8.403
LZs	-33.875	8.403
SEAD	-16.825	8.403
Escort	6.475	8.403
Enemy.Size	88.025	8.403

Interactions

	Effects
Alt:Rtes	-15.475
Alt:LZs	16.175
Alt:SEAD	15.875
Alt:Escort	17.825
Alt:Enemy.Size	-14.675
Rtes:SEAD	-0.725
Rtes:Enemy.Size	13.175

Mean: 383.7125 Standard Error: 5.656564

Table 2. ANOVA Results for Blue RW Detections

All main effects are significant except for Escort. Both Altitude and Enemy Size dominate in the model with MSEs greater by several order of magnitude than the other factors, though Number of Routes and LZs are highly significant. SEAD is found to be significant, but not a dominating factor. Escort is found to be insignificant. This can be attributed to the fact that regardless of the type of escort provided, once in the objective area, where the detections occur, tactics and procedures are the same. Figure 8 depicts the effects of each factor on the mean response.

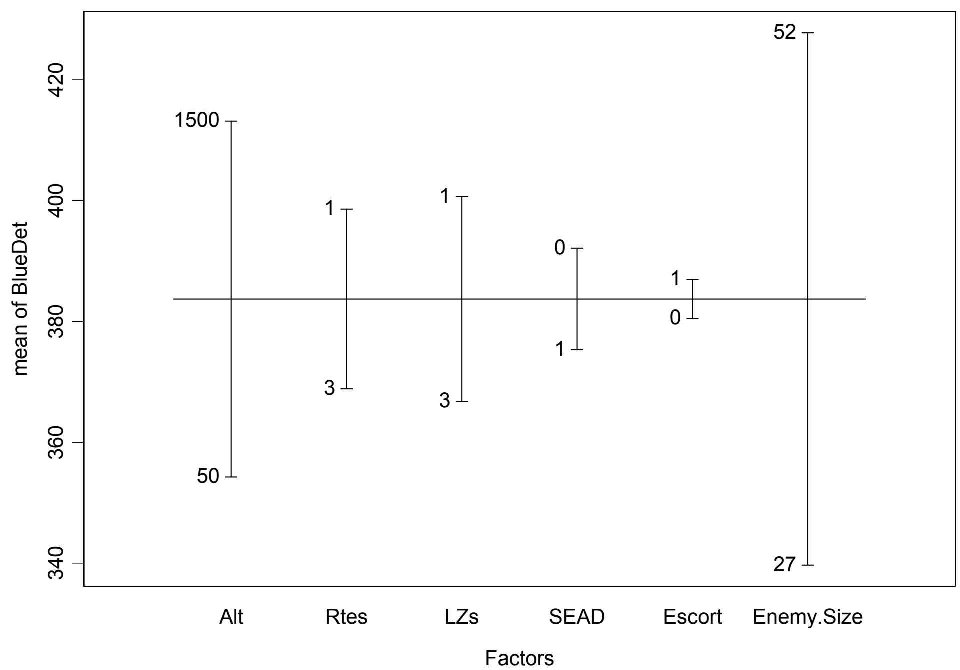

Figure 8. Factor Effects on Mean Blue RW Detections

Both Altitude and Enemy Size significantly increase the number of detections when moved from their lower levels to higher levels. These are not surprising results and are intuitively expected. This will be addressed further in the face validation discussion. Of note, both Number of Routes and Number of LZs significantly decreased the number of detections when increased to three. SEAD had a small effect on detections, which indicates a suppression effect was increased when SEAD was added.

The significant two-way interactions are all those that involve Altitude. Table 3 shows the effect of the Altitude and Number of LZs interaction on the mean number of detections. All figures displayed are the mean number of detections made per mission. When Altitude is set at its lower level the mean response is less than the grand mean, no matter what level the LZ factor is set. This demonstrates how dominant the Altitude factor is in this model. The same effect is present in both the Altitude:SEAD and Altitude:Escort two-way interactions.

1500 (+)	422.0		404.30
Alt		mean = 383.7125	
50 (-)	379.30		329.25
	1 (-)	Number of LZs	3 (+)

Table 3. Two-way interaction effect of Altitude and LZ on mean Blue Detections

2. Analysis of Model Assumptions

The ANOVA model makes the assumptions that errors are normally distributed, with common variance and mean of zero [Ref 14: p. 393]. To ensure our ANOVA results are valid we must check each of these assumptions. Results will also be analyzed to check for outliers that may impact on our results.

Figure 9 depicts a qq-plot of the residuals. It indicates a distribution close to normal, but with a heavy left tail, indicating a positive skew. This is confirmed with a box-plot of residuals for each factor level in figure 10. The median is slightly higher than zero for several of the factors and positive outliers.

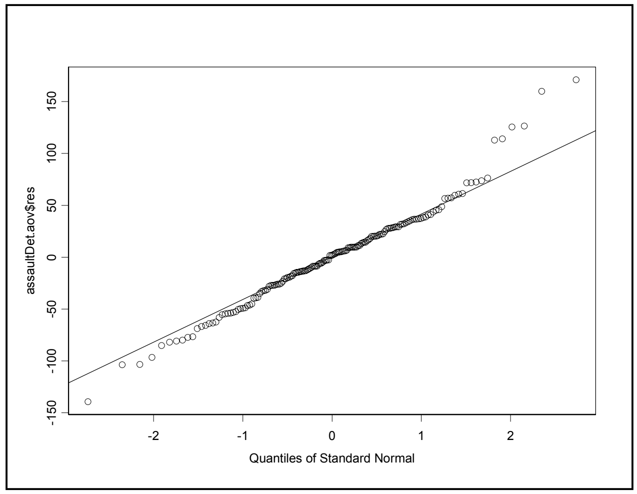

Figure 9. QQ-plot of residuals from Blue RW Detections Response

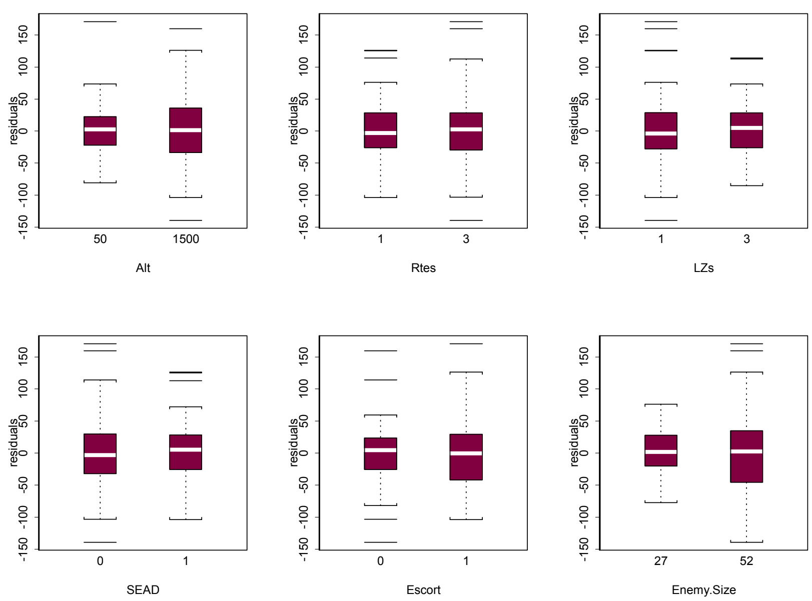

Figure 10. Box-plot of factor levels vs residuals from Blue RW Detections Response

Figure 11 depicts a plot of the residuals (not standardized) versus the fitted values, which will help in diagnosis of common variance. If homoscedasticity exists, the plot will resemble a random plot of points. Our plot shows a stratified structure. This is due to the discrete value of the response variable between 200 and 600 detections. Each line represents a common treatment run. The data throughout are fairly evenly distributed, though there is a wider spread at the high end, due to the seven possible outliers (circled in red) when Altitude and Enemy Size were set at their high levels.

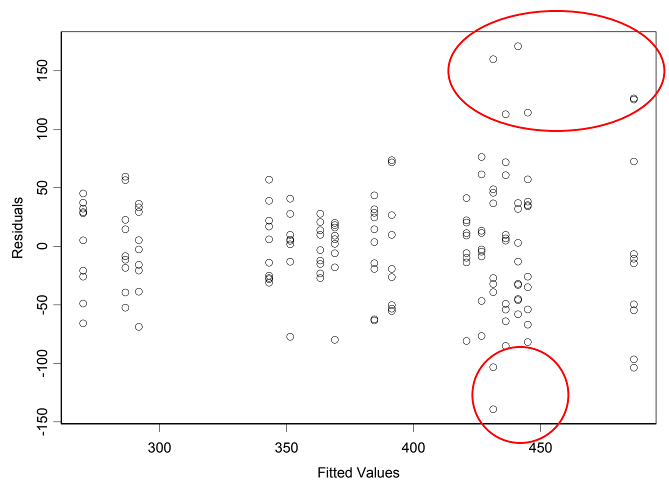

Figure 11. Plot of Fitted values versus Residuals for Blue RW Detections

Figure 12 shows a plot of Cook's distance which helps to identify outliers. Cook's distance is a measure of influence on the model as a whole. It will identify points of high leverage, the potential for influence resulting from unusual response values. A Cook's distance greater than 1 is considered influential [Ref 15: p.130]. All values are below .1, with the highest just above .08. These points appear to be outliers from the residual vs fitted plot (Figure 11) since they lie a greater distance from the mean.

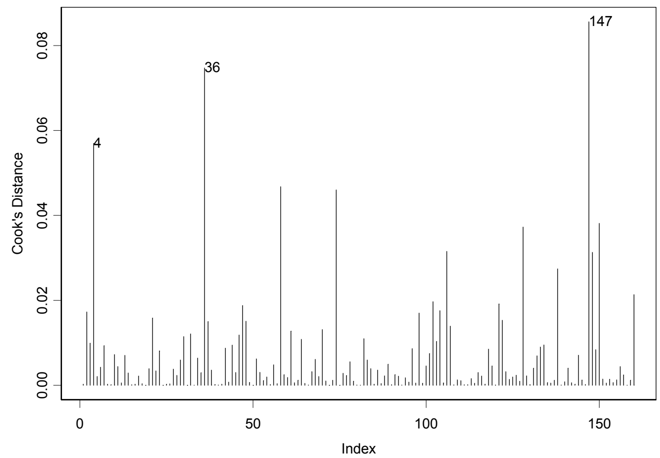

Figure 12. Plot of Cook's distance for Blue RW Detections

The Cook's distance plot demonstrates they do not wield significant influence over the model. There are three points that have potential to be points of high influence. Point 147 from the figure is from treatment run 3 with levels at low altitude and high enemy size with a value of 612 detections (high). Points 4 and 36 are both from treatment run 4 with levels set at high altitude and high enemy size. Point 4 has a value of 292 detections (low) and point 36 has a value of 591 (high). These points differ from the mean value more than other responses, but are not beyond an acceptable range given the tactical circumstances.

Overall, the model meets all the assumptions of ANOVA. The residuals have a distribution close to normal with common variance and a mean of essentially zero. There is some positive skew do to some high observations, but no single point exerts excessive leverage.

C. MOE 2A: BLUE RW ASSAULT KILLS

1. Factor Significance

The ANOVA results for Blue RW Kills are shown in Table 4. Altitude, SEAD and Enemy Size are the only significant factors for main effects. Again Altitude and Enemy Size are the dominating factors. SEAD was determined to be highly significant for this MOE. A surprising result is that the Number of Routes and Number of LZs were found to be insignificant. In fact, increasing the number of both routes and LZs increased

the mean number of Blue RW assault kills. This may be due to the fact that when a single LZ was used, friendly fire power was far more concentrated and combat power was built up at a significantly higher rate.

ANOVA
(Response Variable: Blue RW Assault Kills)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Altitude	1	46.225	46.2250	27.43156	0.0000006
# of Routes	1	0.900	0.9000	0.53409	0.4660627
# of LZs	1	1.225	1.2250	0.72696	0.3952673
SEAD	1	15.625	15.6250	9.27243	0.0027606
Escort	1	2.500	2.5000	1.48359	0.2251786
Enemy.Size	1	96.100	96.1000	57.02916	0.0000000
Alt:Rtes	1	1.225	1.2250	0.72696	0.3952673
Alt:LZs	1	3.600	3.6000	2.13637	0.1459911
Alt:SEAD	1	1.600	1.6000	0.94950	0.3314591
Alt:Escort	1	0.625	0.6250	0.37090	0.5434621
Alt:Enemy.Size	1	38.025	38.0250	22.56539	0.0000048
Rtes:SEAD	1	0.225	0.2250	0.13352	0.7153357
Rtes:Enemy.Size	1	2.500	2.5000	1.48359	0.2251786
Residuals	146	246.025	1.6851		

Main Effects

	Effects	se
Alt	1.075	0.21911
Rtes	0.150	0.21911
LZs	0.175	0.21911
SEAD	-0.625	0.21911
Escort	0.250	0.21911
Enemy.Size	1.550	0.21911

Interactions

	Effects
Alt:Rtes	0.0175
Alt:LZs	-0.30
Alt:SEAD	0.2
Alt:Escort	-0.125
Alt:Enemy.Size	0.975
Rtes:SEAD	-0.075
Rtes:Enemy.Size	0.25

mean: 1.85 Standard Error: 0.1451337

Table 4. ANOVA Results for Blue RW Assault Kills

Figure 13 depicts the factor effects on the mean response of Blue RW Assault Kills. The dominance of both Altitude and Enemy Size can clearly be seen. Escort was found to be insignificant along with Routes and LZs. When SEAD was increased to its high level (adding a Recon scout/sniper team), mean kills was reduced by 1.2, a very significant result. The MSE of Enemy Size is an order of magnitude larger than Altitude and appears to be the dominant factor.

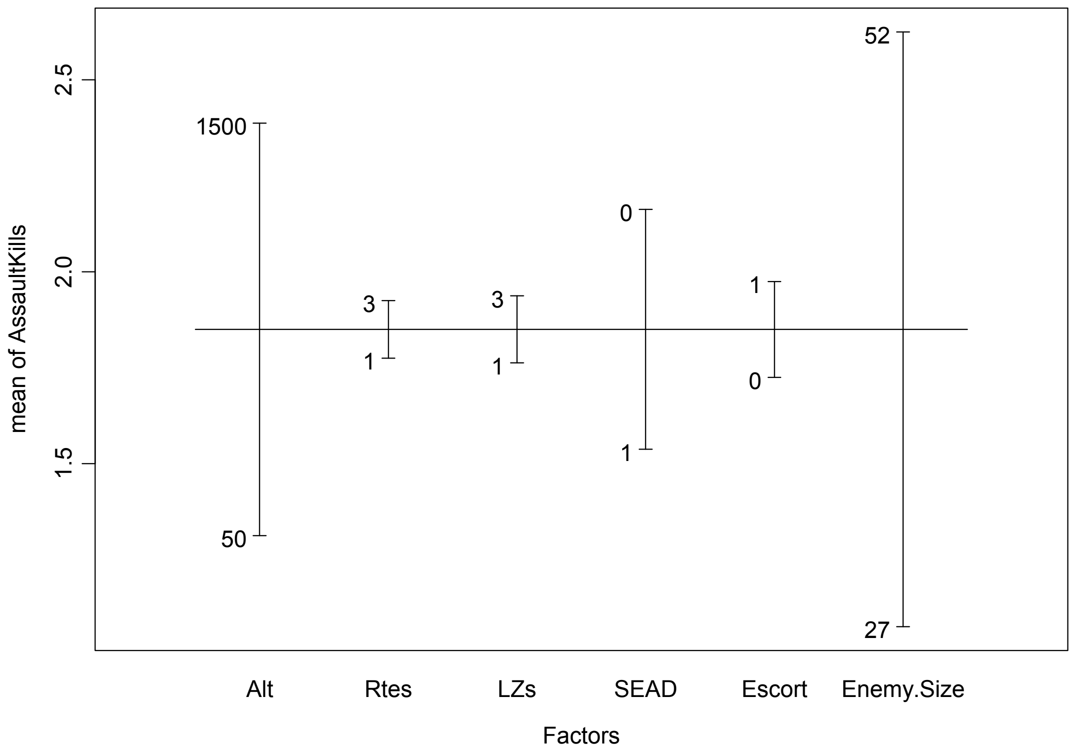

Figure 13. Factor effects on mean Blue RW Assault Kills

The only significant two-way interaction is Altitude and Enemy Size. Table 5 demonstrates the interaction effect on mean kills per mission. When Altitude is low, the mean number of kills is below the mean no matter what level Enemy Size is set at. When altitude is high and Enemy Size is low, mean number of kills is still below the grand mean. When both factors are set at their high levels, the mean number of kills almost triples in number.

	27 (-)		54 (+)
1500 (+)	1.125		3.65
Alt		mean = 1.85	
50 (-)	1.025		1.60
		Enemy Size	

Table 5. Two-way interaction effect of Altitude and Enemy Size on Mean Blue RW Kills

2. Analysis of Model Assumptions

We again use the same techniques to check for model normality, common variance and points of high leverage. Figure 14 depicts the qq-plot of residuals. It has heavy tails due to outliers of both high and low number of kills. The box-plot of residuals for each factor level shown in Figure 15 reinforces the evidence for the existence of a number of low and high outliers. The median is still very close to zero with a value of -0.15. The choppiness in the qq-plot is due to the nature of the integer response variable, which only takes on integer values between 0 and 7.

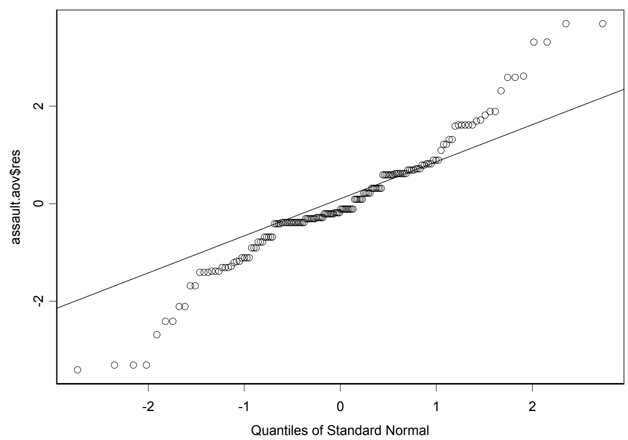

Figure 14. QQ-plot of Blue RW Assault Kills

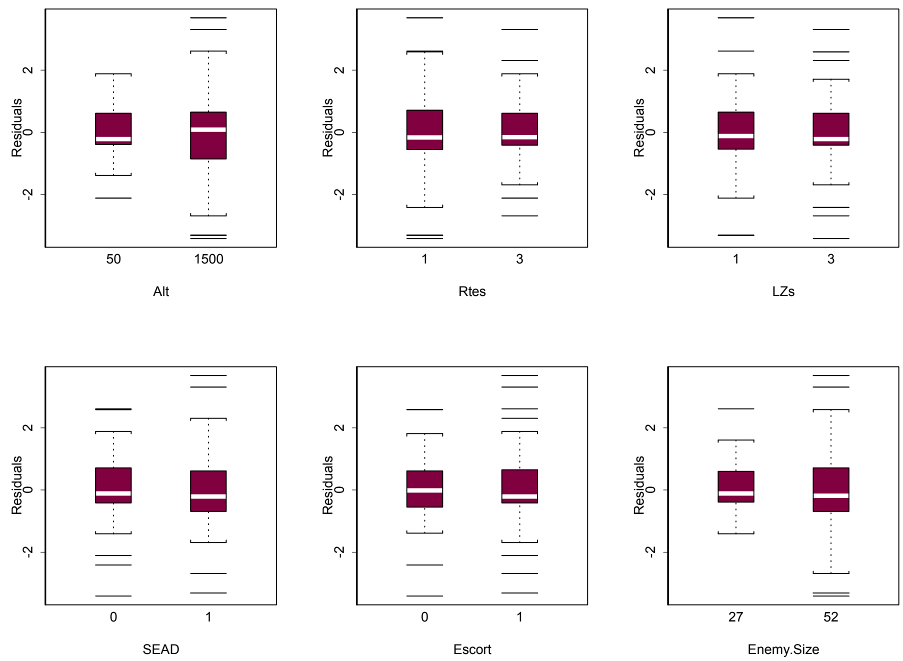

Figure 15. Box-plot of residuals for each factor level

Homoscedasticity was again checked with a plot of the fitted and residual values for the model as shown in Figure 16. This plot is even more stratified than the detection plot. This is again due to the small number of integer values that the response variable can take on. Each column represents a separate treatment run and each row is a common

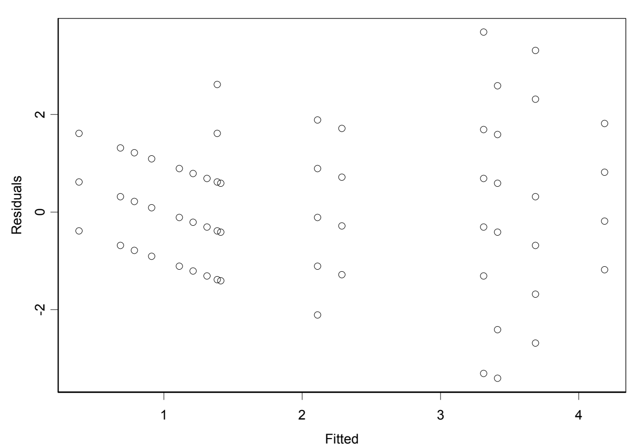

Figure 16. Plot of Fitted versus Residuals for Assault RW Kills

response value. Within each of these columns the data appears to be evenly spread, though there are outliers at the High Altitude and High Enemy Size again. This represents a realistic possible outcome during combat operations.

Figure 17 shows a Cook's distance plot for the Assault kill data. All values are below .06, which indicates they do not have high influence. Data points 106 and 26 are both from treatment 10 and data point 102 is from treatment 6. Both treatments have Altitude and Enemy Size set at the high level. Points 26 and 106 have a value of 7 kills each which is quite high. Point 102 has a value of 0 kills which is quite low for a high altitude and large enemy size run. In all cases the number of kills is not an unrealistic result given the operational scenario.

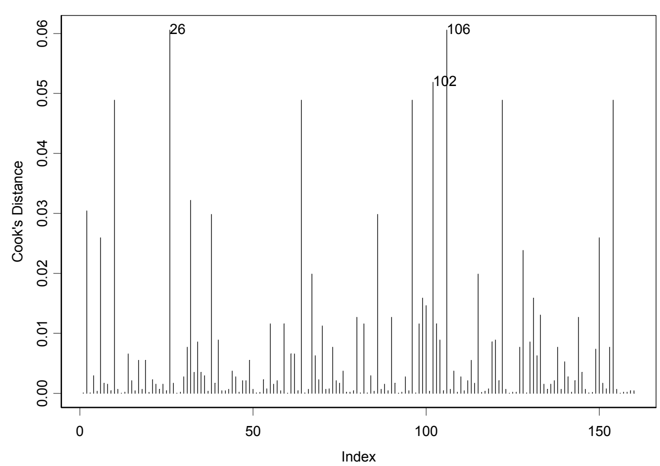

Figure 17. Cook's distance for Blue RW Assault Kill data

In general, the model essentially meets the ANOVA assumptions. There are no points of high leverage or influence, and residuals are close to normal, though there are some outliers causing heavy tails. The assumption of residuals distributed as independent, identically distributed $N(0,\sigma^2)$ appears to hold.

D. MOE 2B: BLUE RW ESCORT KILLS

1. Factor Significance

Table 6 shows the ANOVA results for the Blue Escort kills. It has similar

ANOVA
(Response Variable: Blue RW Escort Kills)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Alt	1	108.900	108.9000	162.1974	0.0000000
Rtes	1	0.625	0.6250	0.9309	0.3362285
LZs	1	0.400	0.4000	0.5958	0.4414455
SEAD	1	2.025	2.0250	3.0161	0.0845524
Escort	1	0.025	0.0250	0.0372	0.8472547
Enemy.Size	1	48.400	48.4000	72.0877	0.0000000
Alt:Rtes	1	0.625	0.6250	0.9309	0.3362285
Alt:LZs	1	2.500	2.5000	3.7235	0.0555898
Alt:SEAD	1	4.225	4.2250	6.2928	0.0132161
Alt:Escort	1	1.225	1.2250	1.8245	0.1788642
Alt:Enemy.Size	1	10.000	10.0000	14.8942	0.0001702
Rtes:SEAD	1	0.000	0.0000	0.0000	1.0000000
Rtes:Enemy.Size	1	0.625	0.6250	0.9309	0.3362285
Residuals	146	98.025	0.6714		

Main Effects

	Effects	se
Alt	0.0022759	0.0001909
Rtes	-0.1250000	0.1383995
LZs	-0.1000000	0.1383995
SEAD	-0.4500000	0.2767989
Escort	0.0500000	0.2767989
Enemy.Size	0.0880000	0.0110720

Interactions

	Effects
Alt:Rtes	-0.0000172412
Alt:LZs	-0.000344824
Alt:SEAD	0.00089655
Alt:Escort	-0.0002413793
Alt:Enemy.Size	0.000482758
Rtes:SEAD	5.72968e-016
Rtes:Enemy.Size	0.01

mean: 2.05 Standard Error: 0.0978632

Table 6. ANOVA Results for Blue Escort Kills

results as assault kills. Altitude and Enemy Size again dominate the model, but this time SEAD is not significant. Number of Routes, Number of LZs and Escort still remain insignificant. Altitude and SEAD as well as Altitude and Enemy Size are significant two-way interactions. One difference for this model is that Altitude MSE is now an order of magnitude larger than Enemy Size; a reversal from the two previous models. Figure 18 depicts the effects of the factors on the response. Altitude's dominance is clearly

displayed. Also, though not significant, the number of escort kills is decreased when the number of Routes and LZs is increased from 1 to 3. This is again a reversal from the previous model of assault kills.

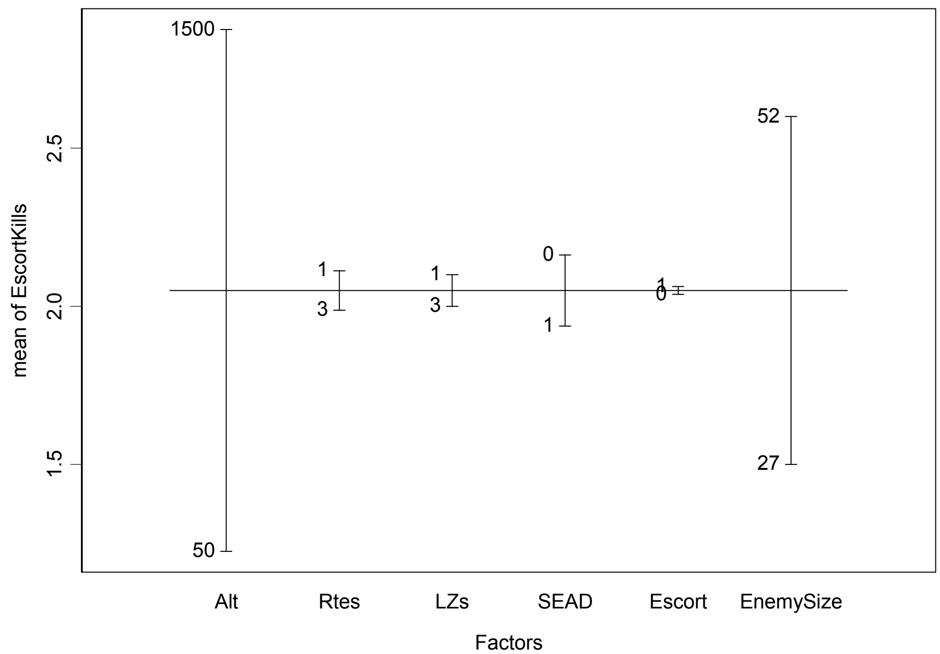

Figure 18. Plot of factor effects on mean Escort Kills

Altitude plays such a dominant effect because the escorts are the first aircraft in the objective area and remain there for the longest period of time. They will typically stay in the objective area after the assault aircraft have left to provide fire support for the GCE. In this scenario they remained in the objective area for 10 minutes after the initial insert. This is the cause for the higher mean number of kills and for the dependence on altitude. Though there may be fewer enemy, when aircraft fly higher and remain in the area for longer periods of time it allows for a greater opportunity to be engaged.

	27 (-)	Enemy Size	54 (+)
1500 (+)	2.075		3.65
Alt		mean = 2.05	
50 (-)	0.925		1.525

Table 7. Two-way interaction effect of Altitude and Enemy Size on Escort Kills

Table 7 shows the two-way interaction effect of Altitude and Enemy Size. It demonstrates the dominance of Altitude. Regardless of the level of enemy size, the mean number of kills is below the mean when Altitude is set to its lower level. And likewise, when Altitude is set to the higher level the mean number of kills is well above the grand mean.

Table 8 depicts the Altitude and SEAD two-way interaction. At low altitude the mean number of kills is well below the mean for both levels of SEAD, but adding SEAD has the effect of reducing mean kills further. At high Altitude this is not the case, as adding SEAD does not reduce the mean number of escort kills. It is increased by a small amount, which is probably due to some outliers, which we will investigate in our model assumption analysis.

	Without (-)	SEAD	with (+)
1500 (+)	2.85		2.925
Alt		mean = 2.05	
50 (-)	1.50		0.95

Table 8. Two-way interaction effect of Altitude and SEAD on mean Escort Kills

2. Analysis of Model Assumptions

Figures 19 and 20 depict the qq-plot and box-plot of residuals by factor level respectively. There is some indication in the tails to outliers. The box-plot confirms this with several outliers in the lower range.

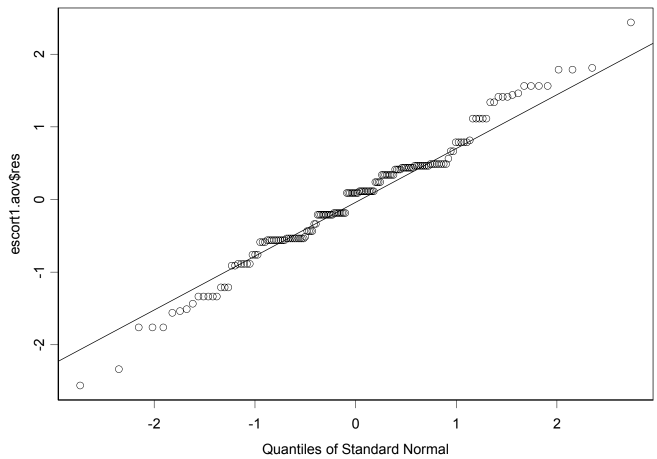

Figure 19. QQ-plot of Residuals for Escort Kills

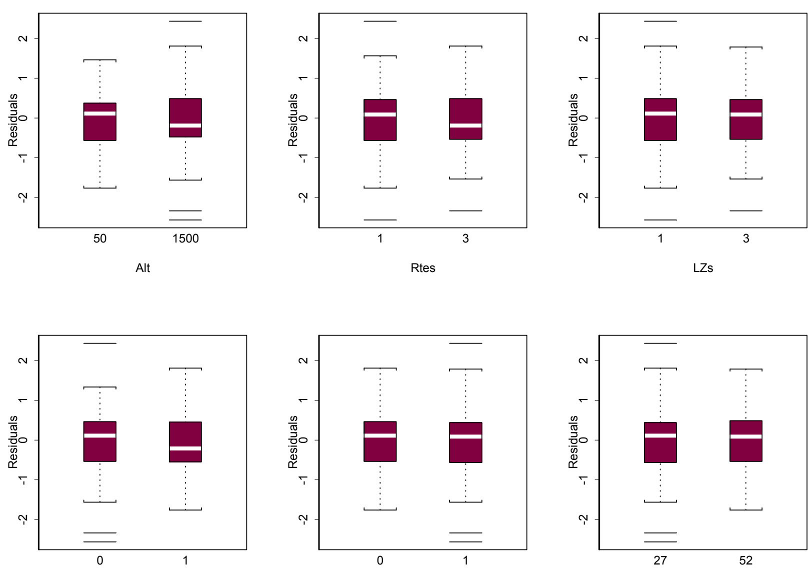

Figure 20. Box-plot of residuals for each factor level

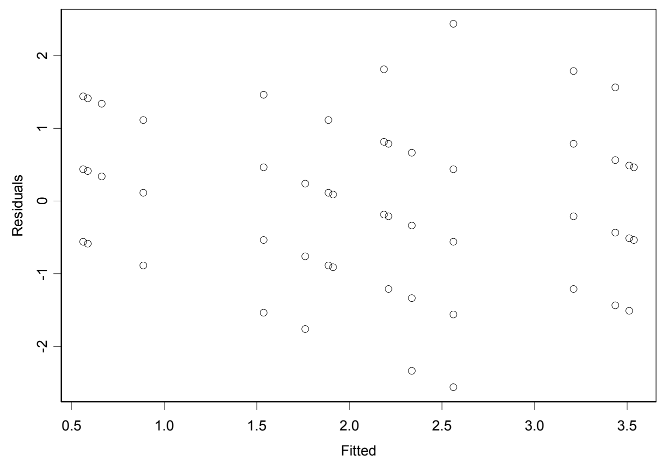

Figure 21. Fitted versus Residual plot for Escort Kills

Figure 21 has the same stratified characteristics seen in earlier trials. The values seem to be fairly well distributed amongst treatment runs, with indication of outliers. The Cook's distance plot in Figure 22 shows all values below 0.06 indicating no points of significant leverage. Points 2, 88 and 114 are all high altitude treatment runs. Points 114 and 88 have 0 kills, while point 2 has 5 kills. These values are also realistic results.

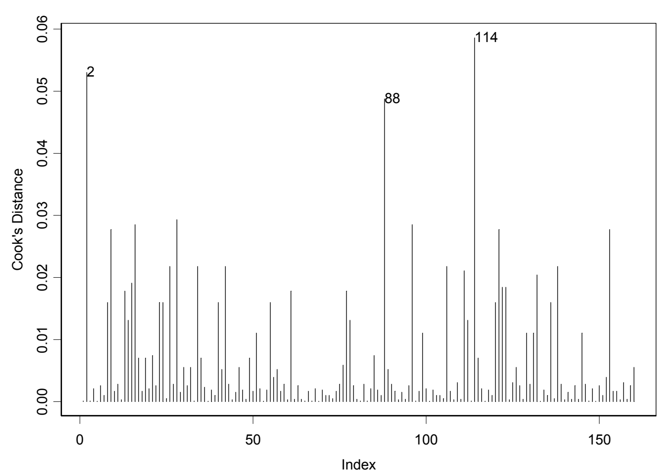

Figure 22. Cook's distance plot for Escort Kills

Overall, our model meets all the assumptions of the ANOVA model. The assumption of residuals distributed as independent, identically distributed $N(0,\sigma^2)$ appears to hold.

E. POWER OF THE TEST

When conducting ANOVA, there are two types of error associated with each hypothesis. Type I error, denoted by α, refers to rejecting the null hypothesis, H_o, when it is true. Type II error, denoted by β, refers to not rejecting the null hypothesis, H_o, when it is false. Type II error reflects the sensitivity of the analysis when H_o is true. The power of the test is defined as $(1-\beta)$, or the probability of rejecting the null hypothesis, given it is false [Ref 16: p. 21]. If the variance of the response variable can be estimated, then β can be calculated for a given level of deviation from the response mean.

The power of the test was calculated for each of the MOEs for a 1,3 and 5 percent deviation from the response mean and results are displayed in Table 9. An alpha level of .05 was assumed. Results indicate a .001 or lower probability of committing a Type II error at a 5% deviation from the mean for both RW Detections and Escort Kills, and a .02 probability for RW Assault Kills. This indicates that we have conducted enough replications to ensure rejecting the null hypothesis when it is false at a reasonable level.

% Deviation from Response Mean	RW Detections	Assault Kills	Escort Kills
1%	.9884	.1262	.2988
3%	.9999	.6639	.9902
5%	.9999	.9797	.9999

Table 9. Power of Test for MOEs

F. VARYING THE NUMBER OF LANDING ZONES

Finding the number of routes and LZs insignificant appeared to be counter-intuitive. We decided to make some further investigations into this issue by fixing all factors at acceptable levels and making two scenario runs; one with a single LZ into the objective area and the second with three LZs into the objective area. Table 9 below depicts the experimental design for the two scenario runs. Ten replications of each run were completed. A two-sample t-test was the used to determine if there was any significant difference between the mean number of aircraft kills or detections for the two simulation runs.

1 Landing Zone		3 Landing Zones	
Factor	Level	Factor	Level
Altitude	Low (-)	Altitude	Low (-)
Routes	3 (+)	Routes	3 (+)
SEAD	Use (+)	SEAD	Use (+)
Escort	Detached (-)	Escort	Detached (-)
Enemy Size	27 (-)	Enemy Size	27 (-)

Table 10. Experimental design for varying the number of LZs

1. Two-sample T-test

The two-sample t-test is based on the student's t distribution and requires the assumption that the samples distributions are independent, normally distributed with common variance. The t-test tests the hypothesis: Ho: $\bar{X} - \bar{Y} = 0$. The alternative hypothesis being: Ha: $\bar{X} - \bar{Y} \neq 0$. The null hypothesis is accepted if $t < t_{\alpha/2, m+n-2}$ or $t > -t_{\alpha/2, m+n-2}$ [Ref 13: p.358-9].

2. Findings

The results from the 20 runs are listed in Table 10 below. T-tests were conducted on assault aircraft kills, escort aircraft kills and detections. We also looked at the number of GCE kills to see if the number of LZs had any effect on their mission. In all four cases the findings were unremarkable. There was found to be no significant difference in means for one LZ or three LZs for any of the MOEs. The raw data results from the runs are listed in Appendix D.

There could be two explanations for this. The first is the same argument mentioned earlier, that the use of one LZ allows for concentration of blue firepower and rapid buildup of Blue combat power in a single location. The other is that it could be due to the way the simulation calculates attrition when forces are aggregated. When more forces are concentrated into a single location their firepower is more effective and less vulnerable to enemy fire.

	Assault Kills		Escort Kills		Detections		GCE Kills	
	1 LZ	3 LZs	1 LZ	3 LZs	1 LZ	3 LZs	1 LZ	3 LZs
Mean	.5	.4	.8	1.1	201.5	200.6	16.5	16.0
t	0.3612		0.9762		0.0649		0.1215	
p-value	0.7222		0.3419		0.949		0.9047	
95% CI	[-.482 , .682]		[-.946 , .346]		[-28.24 , 30.04]		[-8.147, 9.147]	

Table 11. Results from t-test of 1 and 3 LZ simulation runs

G. SIMULATION FACE VALIDATION

To conduct our face validation we concentrated on four areas; aircraft casualty rates, GCE casualty rates, kill shot realism and movement rates. Two tables were generated from simulation results to help depict the aircraft kill rates. Table 12 shows the mean number of aircraft kills by factor level. Table 13 shows the aircraft casualty rates for assault aircraft, escort aircraft and combined rate by factor level.

The results for aircraft kills appear to be realistic given the tactical scenario. The overall mean number of kills for both assault and escort aircraft is about 2. When analyzing the mean kills by factor levels, the outcomes are consistent with the input factor levels. For example, when aircraft altitude is moved from low to high level the mean number of aircraft kills almost double for assault and more than doubles for escort aircraft. This is intuitively the expected outcome. The same is true for enemy size.

	Mean Assault Kills	Mean Escort Kills
Low Altitude	1.31	1.09
High Altitude	2.39	2.88
1 Route	1.78	2.11
3 Route	1.93	1.60
1 LZ	1.76	2.10
3 LZ	1.94	2.00
No SEAD	2.16	2.16
SEAD	1.54	1.94
Attached Escort	1.975	2.06
Detached Escort	1.73	2.04
2:1 Force Ratio	1.08	1.50
3:1 Force Ratio	2.63	2.60

Table 12. Mean Aircraft Kills by factor level

The overall casualty rate for assault aircraft is 15% while the escorts have a 40% casualty rate. This higher rate is due to the amount of time spent in the objective area. This again is a realistic outcome. One area of concern is the casualty rate difference at the differing LZ levels. This is not necessarily an intuitive result. More research needs to be conducted before a definitive answer can be reach.

	Assault Casualty Rate	Escort Casualty Rate	Combined
Low Altitude	0.1092	0.2188	0.1640
High Altitude	0.1992	0.5750	0.3871
1 Route	0.1483	0.4225	0.2854
3 Routes	0.1608	0.3209	0.2409
1 LZ	0.1467	0.4200	0.2833
3 LZs	0.1617	0.4000	0.2808
No SEAD	0.1800	0.4325	0.3063
SEAD	0.1283	0.3875	0.2579
Attached Escort	0.1646	0.4125	0.2885
Detached Escort	0.1442	0.4075	0.2758
2:1 Force Ratio	0.0900	0.3000	0.1950
3:1 Force Ratio	0.2192	0.5200	0.3696
Overall mean	0.1543	0.4014	0.2779

Table 13. Aircraft Casualty Rates by Factor level

We conducted qualitative analysis of the kill shot ranges (in meters) to ensure that the weapon systems were making realistic shots. Figures 23 and 24 depict Red and Blue kill shot ranges respectively. Of note, the x-axis depicts the shot number, not the number of shots taken. Each range is one shot. All of the shots taken by each weapon system are with their respective ranges and capabilities, though there are a couple of shots by the RPG and AT-4 that are at quite a distance considering the environment. Overall, the shots are within the maximum effective range. Blue side shots are realistic as well. There is only one shot where the AH-1W 20mm made a kill at 800 meters. This is within the capability of the weapon system, but at the far end of the engagement envelope for an urban environment. The simulation overall, appeared to give realistic results for the RW operations. Appendix E contains screen captures of simulation runs from this scenario.

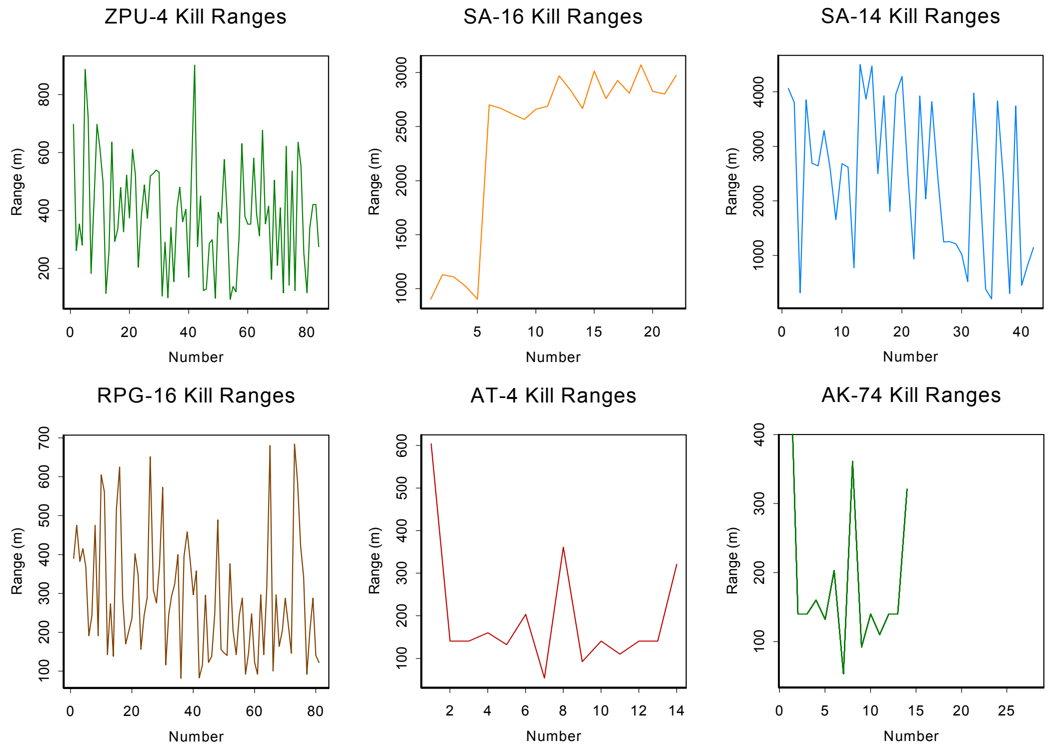

Figure 23. Red shot kill ranges by weapon system

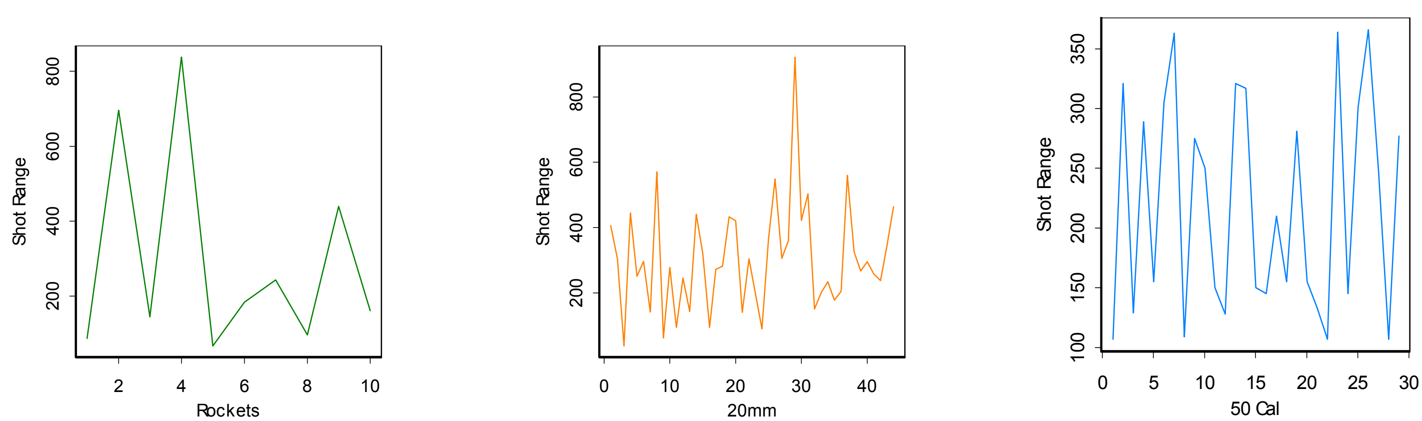

Figure 24. Blue shot kill ranges by weapon system

The focus of this thesis was not on infantry operations, but we looked at our results of Blue GCE kills to get a qualitative sense of how the simulation depicts infantry combat in an urban environment. Ground force operations were carried out for 15 minutes after insertion into objective LZs. Table 14 shows the GCE kills and casualty rates for the twenty replications completed from the scenario runs where the number of LZs were varied. The over all rate is 15 %, which is half of the historical urban casualty rate of 30% [Ref 9: p. 5]. This does not appear to be realistic. It may be due to the fact that most of the ground forces were left in squad aggregates and not modeled individually with the exception of three squads that entered buildings.

Replication	Blue GCE Kills	GCE casualty Rate
1	6	0.0545
2	8	0.0727
3	19	0.1727
4	9	0.0818
5	33	0.3000
6	24	0.2182
7	11	0.1000
8	3	0.0273
9	32	0.2909
10	20	0.1818
1	28	0.2545
2	9	0.0818
3	21	0.1909
4	11	0.1000
5	25	0.2273
6	8	0.0727
7	11	0.1000
8	15	0.1364
9	10	0.0909
10	22	0.2000
	overall	0.1477

Table 14. Blue GCE casualty rates

This leads us to the Blue GCE movement rate. From insert at the LZs (approximately 200 meters from objective) to movement to the objective buildings it took the ground forces no longer than fifteen minutes to clear the objective. This appears to be

much too fast. Again this may be due to the level of aggregation of the forces. JCATS allows for suppression of forces which does slow rates considerably for individual entities, but the aggregated forces did not appear to be quite as affected.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

To review, the objectives of this thesis are listed below, each of which will be addressed in the following paragraphs.

- Evaluate rotary wing survivability in an urban environment
- Determine major factors that impact on survivability
- Evaluate effect of urban SEAD on R/W survivability
- Evaluate JCATS as an urban operations modeling tool
- Give insight into development of doctrine and TTPs for urban R/W operations

1. Rotary Wing Survivability

Given the tactical circumstances of this scenario, rotary wing aircraft are survivable in an urban environment. The GCE no-go criteria (less than 8 CH-46E equivalents in zone) was never met. Of the 180 total runs made, seven assault kills (the highest number of assault aircraft killed) was achieved 3 times. The highest number of assaults killed at low altitude was 4. Escort aircraft endured a higher casualty rate, but this is to be expected given the nature of their mission. If proper tactical procedures are followed RW aircraft will survive in urban combat.

2. Major Factors of Influence

For assault aircraft, Altitude and SEAD proved to be the significant factors for survival. Altitude, number of routes, number of LZs and SEAD presence influenced detection rate of these aircraft. Detection rates can be lowered significantly if profiles are flown at low altitude, with multiple avenues of approach and LZs as well the use of SEAD. Escort aircraft fared the best when in low altitude profiles. Though not statistically significant at our alpha level, SEAD did generally improve survivability.

Of note, the number of routes and LZs did not influence aircraft kill rates in this scenario. The routing was not significant since threats were not encountered until aircraft

were in the objective area. LZ results may be reflective of the small objective area used in this scenario.

3. SEAD Effectiveness

The use of SEAD (scout/sniper team) was found to be significant for RW survivability. The presence of SEAD lowered the mean number of assault aircraft kills by 17% and lowered the number of escort kills by 11%. SEAD was also found to have an impressive suppression affect for lowering the number of detections. This is an encouraging result and should lead to the refinement of SEAD tactics in the urban environment.

4. JCATS Face Validation

Our qualitative results considering simulation realism are encouraging. From the standpoint of RW aircraft, the model outputs appear to be realistic. When Altitude and Enemy level were increased to their higher levels, resulting casualty and detection rates were expectedly higher. The acquisitions and kill shots of all weapon systems were realistic and within the capabilities of the system being modeled. Overall, the output for RW urban operations seems to be realistic.

This simulation was designed as a modeling tool for combat systems to explore tactics and procedures as well as a training tool for military staffs. It is an excellent platform for these uses and further research needs to continue.

5. Tactical Insights

The use of scout/sniper teams for urban RW operations is the most encouraging result from this study. Their addition significantly lowered aircraft kill rates. The intuitive use of low altitude flight profiles was confirmed. The surprising result of the insignificance of the number of LZs and routes needs to be looked at further. Their use when conducting multiple waves may be effective. Unfortunately there was not enough time in this study to conduct analysis on such operations.

B. RECOMMENDATIONS

1. Urban Rotary Wing Tactics

The use of scout/sniper teams as urban SEAD needs to be utilized whenever possible. Their use will help ensure the survivability of aircraft as well as the ground

force conducting the operation. Tactics utilizing multiple routes and LZs should not be discarded. This study found them insignificant when attacking a single objective with the enemy force concentrated in a small area. This may not always be the situation and METT-T factors will apply. Marine Corps altitude doctrine is sound. When enemy threat dictates or is unknown, low altitude profiles should be maintained. Fleet operational studies need to incorporate these tactics to ensure their validity and refine their use.

2. Urban Combat Simulation

The JCATS combat model provides excellent features for modeling urban combat. Street, building and subterranean features allow for detailed modeling of urban areas. Systems can be modeled in great detail to produce realistic outcomes. Urban modeling research needs to continue using this simulation for both insights and simulation validity. This modeling platform could contribute significantly to tactical doctrine in urban environments for both rotary wing and infantry operations.

One weakness in the simulation appeared to be in the casualty rate assessed by the model. This was not a detailed study of ground operations, so further research needs to be conducted to evaluate ground combat operations modeled by this simulation.

C. FURTHER RESEARCH

This thesis only covered a small fraction of urban operations. There are several areas of research that could be pursued as follow-on studies, particularly regarding rotary wing operations. Some areas of study are included below.

1. Urban Rotary Wing Operations

Detailed research could be done on rotary wing survivability in urban combat when multiple waves of aircraft are required. Survivability needs to be looked at as a function of time in the objective area. Aircraft may be survivable when conducting operations with limited time in the vicinity of the threat, but with prolonged exposure this may not be possible. Multiple avenues of approach and LZs may play a critical role in such a setting. Varying the number of LZs as well as changing LZs during each wave could be studied for effectiveness. Rotary wing CAS and night operations are other areas where simulation work could give insight into what tactics are effective.

2. Urban Infantry Operations and Model Validation

Insight could be gained from modeling ground operations in urban settings as well. This thesis did not focus on these operations, but tactical and doctrinal gains could be achieved by conducting studies in this area with the use of JCATS. To ensure accurate results, much more research needs to be conducted into the validity of JCATS. To do this, real world data is needed. Fully instrumented (both ground and aviation) training events need to be conducted at MOUT sites to gather this information to use as a baseline for comparison. In addition, detailed studies need to be completed on the simulation inputs. Though the face validation conducted in this thesis found output to be realistic, algorithms for acquisition, line of sight and engagement adjudication all need to be studied in order to evaluate their accuracy and validity.

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APPENDIX A. ASSAULT SUPPORT DECISION MATRIX

The table below shows an example of the Assault Support Decision Matrix. Members of the planning staff would fill out the table upon completion of COA development to aid in the decision of choosing a COA. Each factor in the matrix is rated by 1 for good, 2 neutral and 3 worst. Repeat values are possible for different COAs. Factors that are equal get the same rating. The standard practice is to determine the average number for each COA. The one with the lowest average has the greatest chance of success. A more complicated scheme could be devised to weight the factors according to importance for a particular mission.

COAs:	**COA 1**	**COA 2**	**COA 3**
Air route not subject to enemy fire & observation			
Enemy locations and reaction time to LZ			
LZ under friendly eyes			
LZ not accessible to vehicles			
Hides near the LZ			
Distance to objective to the LZ			
C2 routes to objective			
Objective hot or cold			
Doctrinal application			
Length of time till link-up with ground forces			
RISK:			

Assault Support Decision Matrix

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APPENDIX B. 2^{6-2} FACTORIAL DESIGN

Factorial Design:

```
Resolution: IV
Runs:        16
Fraction:   1/4
```

Run	Altitude	Routes	LZs	SEAD	Escort	Enemy Size
1	50	1	1	0	Detached	27
2	1500	1	1	0	Attached	27
3	50	3	1	0	Attached	54
4	1500	3	1	0	Detached	54
5	50	1	3	0	Attached	54
6	1500	1	3	0	Detached	54
7	50	3	3	0	Detached	27
8	1500	3	3	0	Attached	27
9	50	1	1	1	Detached	54
10	1500	1	1	1	Attached	54
11	50	3	1	1	Attached	27
12	1500	3	1	1	Detached	27
13	50	1	3	1	Attached	27
14	1500	1	3	1	Detached	27
15	50	3	3	1	Detached	54
16	1500	3	3	1	Attached	54

```
Design Generators:  E = ABC   F = BCD

Alias Structure

I + ABCE + ADEF + BCDF

A + BCE + DEF + ABCDF
B + ACE + CDF + ABDEF
C + ABE + BDF + ACDEF
D + AEF + BCF + ABCDE
E + ABC + ADF + BCDEF
F + ADE + BCD + ABCEF
AB + CE + ACDF + BDEF
AC + BE + ABDF + CDEF
AD + EF + ABCF + BCDE
AE + BC + DF + ABCDEF
AF + DE + ABCD + BCEF
BD + CF + ABEF + ACDE
BF + CD + ABDE + ACEF
ABD + ACF + BEF + CDE
ABF + ACD + BDE + CEF
```

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APPENDIX C. FACTORIAL DESIGN RESULTS

Run	Alt	Rtes	LZs	SEAD	Escort	Enemy Size	Escort Kills	Assault Kills	Blue Det
1	50	1	1	0	0	27	1	1	373
2	1500	1	1	0	1	27	5	4	350
3	50	3	1	0	1	52	2	2	383
4	1500	3	1	0	0	52	4	5	292
5	50	1	3	0	1	52	2	2	365
6	1500	1	3	0	0	52	3	1	483
7	50	3	3	0	0	27	1	2	343
8	1500	3	3	0	1	27	1	2	361
9	50	1	1	1	0	52	0	1	415
10	1500	1	1	1	1	52	3	0	437
11	50	3	1	1	1	27	0	0	253
12	1500	3	1	1	0	27	2	1	329
13	50	1	3	1	1	27	2	1	221
14	1500	1	3	1	0	27	1	2	416
15	50	3	3	1	0	52	3	2	375
16	1500	3	3	1	1	52	5	4	446
1	50	1	1	0	0	27	0	0	336
2	1500	1	1	0	1	27	3	1	438
3	50	3	1	0	1	52	1	1	444
4	1500	3	1	0	0	52	4	4	468
5	50	1	3	0	1	52	1	3	465
6	1500	1	3	0	0	52	3	4	479
7	50	3	3	0	0	27	2	1	234
8	1500	3	3	0	1	27	1	2	353
9	50	1	1	1	0	52	2	1	430
10	1500	1	1	1	1	52	5	7	476
11	50	3	1	1	1	27	0	1	328
12	1500	3	1	1	0	27	4	1	315
13	50	1	3	1	1	27	1	1	315
14	1500	1	3	1	0	27	3	0	322
15	50	3	3	1	0	52	1	0	371
16	1500	3	3	1	1	52	4	1	372
1	50	1	1	0	0	27	1	2	360
2	1500	1	1	0	1	27	1	0	380
3	50	3	1	0	1	52	1	3	473
4	1500	3	1	0	0	52	3	5	591
5	50	1	3	0	1	52	2	2	463
6	1500	1	3	0	0	52	4	6	410
7	50	3	3	0	0	27	1	2	278
8	1500	3	3	0	1	27	1	0	356
9	50	1	1	1	0	52	1	1	411
10	1500	1	1	1	1	52	5	3	432
11	50	3	1	1	1	27	0	0	276
12	1500	3	1	1	0	27	2	0	400
13	50	1	3	1	1	27	1	2	302
14	1500	1	3	1	0	27	3	1	321
15	50	3	3	1	0	52	2	2	289
16	1500	3	3	1	1	52	3	3	508

1	50	1	1	0	0	27	0	0	348
2	1500	1	1	0	1	27	3	1	424
3	50	3	1	0	1	52	3	2	395
4	1500	3	1	0	0	52	4	4	399
5	50	1	3	0	1	52	2	3	372
6	1500	1	3	0	0	52	4	3	419
7	50	3	3	0	0	27	2	3	278
8	1500	3	3	0	1	27	3	2	392
9	50	1	1	1	0	52	1	0	432
10	1500	1	1	1	1	52	3	3	613
11	50	3	1	1	1	27	0	2	321
12	1500	3	1	1	0	27	2	1	318
13	50	1	3	1	1	27	2	0	204
14	1500	1	3	1	0	27	2	2	370
15	50	3	3	1	0	52	1	1	389
16	1500	3	3	1	1	52	3	7	497
1	50	1	1	0	0	27	1	1	351
2	1500	1	1	0	1	27	3	1	422
3	50	3	1	0	1	52	2	0	408
4	1500	3	1	0	0	52	4	3	477
5	50	1	3	0	1	52	2	3	418
6	1500	1	3	0	0	52	4	5	378
7	50	3	3	0	0	27	1	1	268
8	1500	3	3	0	1	27	2	1	353
9	50	1	1	1	0	52	2	2	441
10	1500	1	1	1	1	52	3	4	612
11	50	3	1	1	1	27	0	1	289
12	1500	3	1	1	0	27	3	0	312
13	50	1	3	1	1	27	2	1	298
14	1500	1	3	1	0	27	1	1	428
15	50	3	3	1	0	52	1	1	387
16	1500	3	3	1	1	52	3	2	441
1	50	1	1	0	0	27	1	1	360
2	1500	1	1	0	1	27	2	3	488
3	50	3	1	0	1	52	2	2	396
4	1500	3	1	0	0	52	4	5	468
5	50	1	3	0	1	52	1	2	401
6	1500	1	3	0	0	52	4	6	480
7	50	3	3	0	0	27	1	1	275
8	1500	3	3	0	1	27	0	2	379
9	50	1	1	1	0	52	1	1	462
10	1500	1	1	1	1	52	4	5	480
11	50	3	1	1	1	27	1	1	321
12	1500	3	1	1	0	27	2	1	316
13	50	1	3	1	1	27	1	1	275
14	1500	1	3	1	0	27	2	0	409
15	50	3	3	1	0	52	1	1	385
16	1500	3	3	1	1	52	5	7	382

1	50	1	1	0	0	27	1	1	377
2	1500	1	1	0	1	27	3	3	503
3	50	3	1	0	1	52	3	4	428
4	1500	3	1	0	0	52	4	6	392
5	50	1	3	0	1	52	2	2	341
6	1500	1	3	0	0	52	4	0	363
7	50	3	3	0	0	27	1	3	346
8	1500	3	3	0	1	27	2	0	274
9	50	1	1	1	0	52	2	1	407
10	1500	1	1	1	1	52	5	7	383
11	50	3	1	1	1	27	1	0	223
12	1500	3	1	1	0	27	2	0	349
13	50	1	3	1	1	27	0	1	249
14	1500	1	3	1	0	27	2	0	365
15	50	3	3	1	0	52	0	1	363
16	1500	3	3	1	1	52	2	3	443
1	50	1	1	0	0	27	1	0	340
2	1500	1	1	0	1	27	0	2	440
3	50	3	1	0	1	52	1	0	409
4	1500	3	1	0	0	52	4	4	404
5	50	1	3	0	1	52	2	2	401
6	1500	1	3	0	0	52	4	3	391
7	50	3	3	0	0	27	1	0	247
8	1500	3	3	0	1	27	1	0	357
9	50	1	1	1	0	52	0	0	340
10	1500	1	1	1	1	52	2	0	559
11	50	3	1	1	1	27	2	0	325
12	1500	3	1	1	0	27	2	1	365
13	50	1	3	1	1	27	0	1	244
14	1500	1	3	1	0	27	3	1	413
15	50	3	3	1	0	52	1	0	351
16	1500	3	3	1	1	52	3	6	549
1	50	1	1	0	0	27	2	1	391
2	1500	1	1	0	1	27	2	0	418
3	50	3	1	0	1	52	3	4	478
4	1500	3	1	0	0	52	2	3	480
5	50	1	3	0	1	52	2	4	336
6	1500	1	3	0	0	52	4	4	502
7	50	3	3	0	0	27	1	1	301
8	1500	3	3	0	1	27	1	2	338
9	50	1	1	1	0	52	2	0	441
10	1500	1	1	1	1	52	5	2	390
11	50	3	1	1	1	27	0	0	297
12	1500	3	1	1	0	27	2	2	360
13	50	1	3	1	1	27	1	2	307
14	1500	1	3	1	0	27	2	1	399
15	50	3	3	1	0	52	1	2	378
16	1500	3	3	1	1	52	3	2	387

1	50	1	1	0	0	27	2	2	384
2	1500	1	1	0	1	27	2	1	418
3	50	3	1	0	1	52	2	2	612
4	1500	3	1	0	0	52	4	4	328
5	50	1	3	0	1	52	2	1	338
6	1500	1	3	0	0	52	3	1	559
7	50	3	3	0	0	27	1	2	309
8	1500	3	3	0	1	27	3	1	338
9	50	1	1	1	0	52	0	2	443
10	1500	1	1	1	1	52	3	0	472
11	50	3	1	1	1	27	1	0	271
12	1500	3	1	1	0	27	2	1	382
13	50	1	3	1	1	27	0	1	299
14	1500	1	3	1	0	27	2	1	388
15	50	3	3	1	0	52	1	1	389
16	1500	3	3	1	1	52	4	4	351

APPENDIX D. VARYING LZ RUN RESULTS

Run	# LZs	Assault Kills	Escort Kills	Aircraft Detections	Blue GCE Kills
1	1	0	1	159	6
2	1	0	1	209	8
3	1	0	1	250	19
4	1	1	0	204	9
5	1	1	1	178	33
6	1	1	2	182	24
7	1	0	0	145	11
8	1	1	0	261	3
9	1	0	1	203	32
10	1	1	1	224	20
1	3	0	2	150	28
2	3	1	2	213	9
3	3	1	0	213	21
4	3	0	1	217	11
5	3	0	1	197	25
6	3	0	0	193	8
7	3	2	1	211	11
8	3	0	1	175	15
9	3	0	2	206	10
10	3	0	1	231	22

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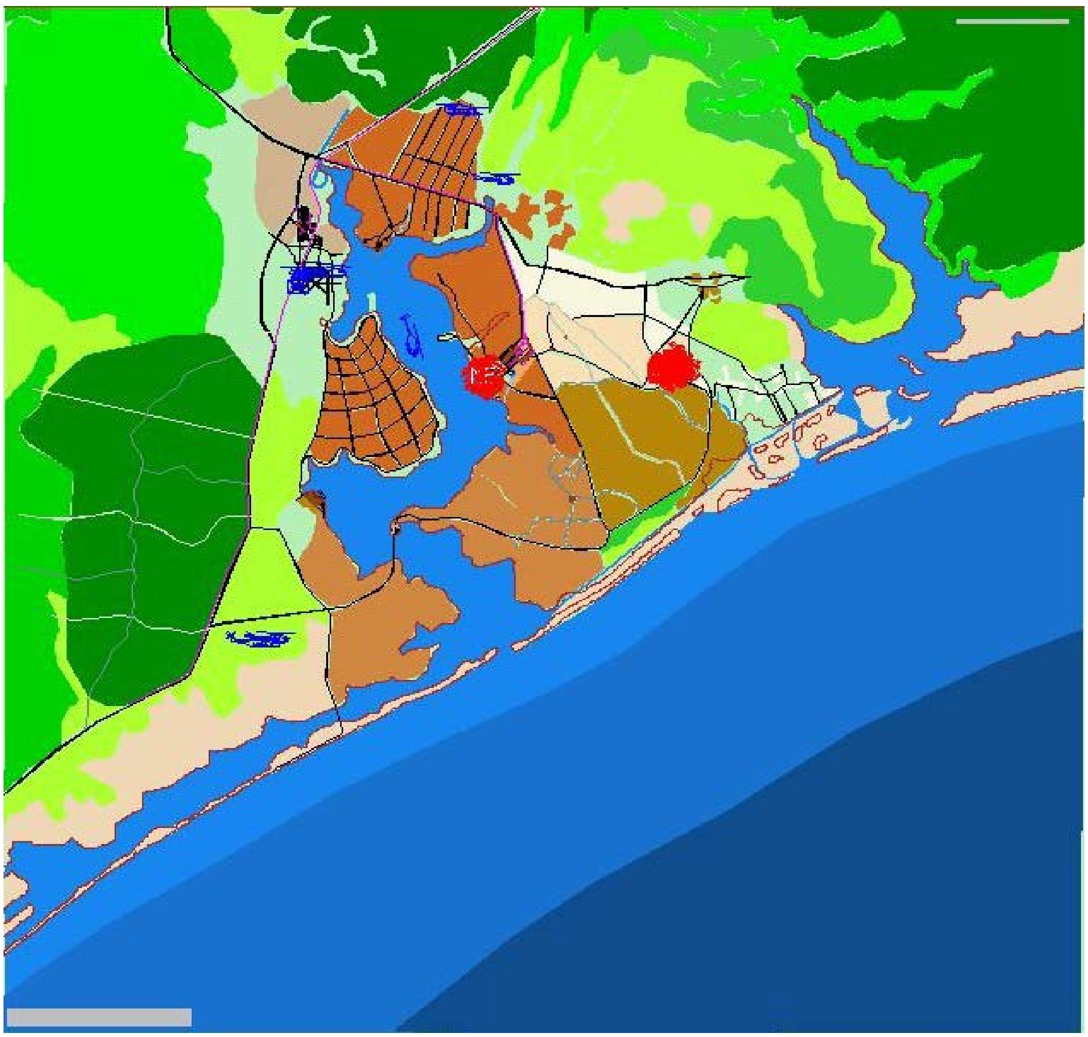
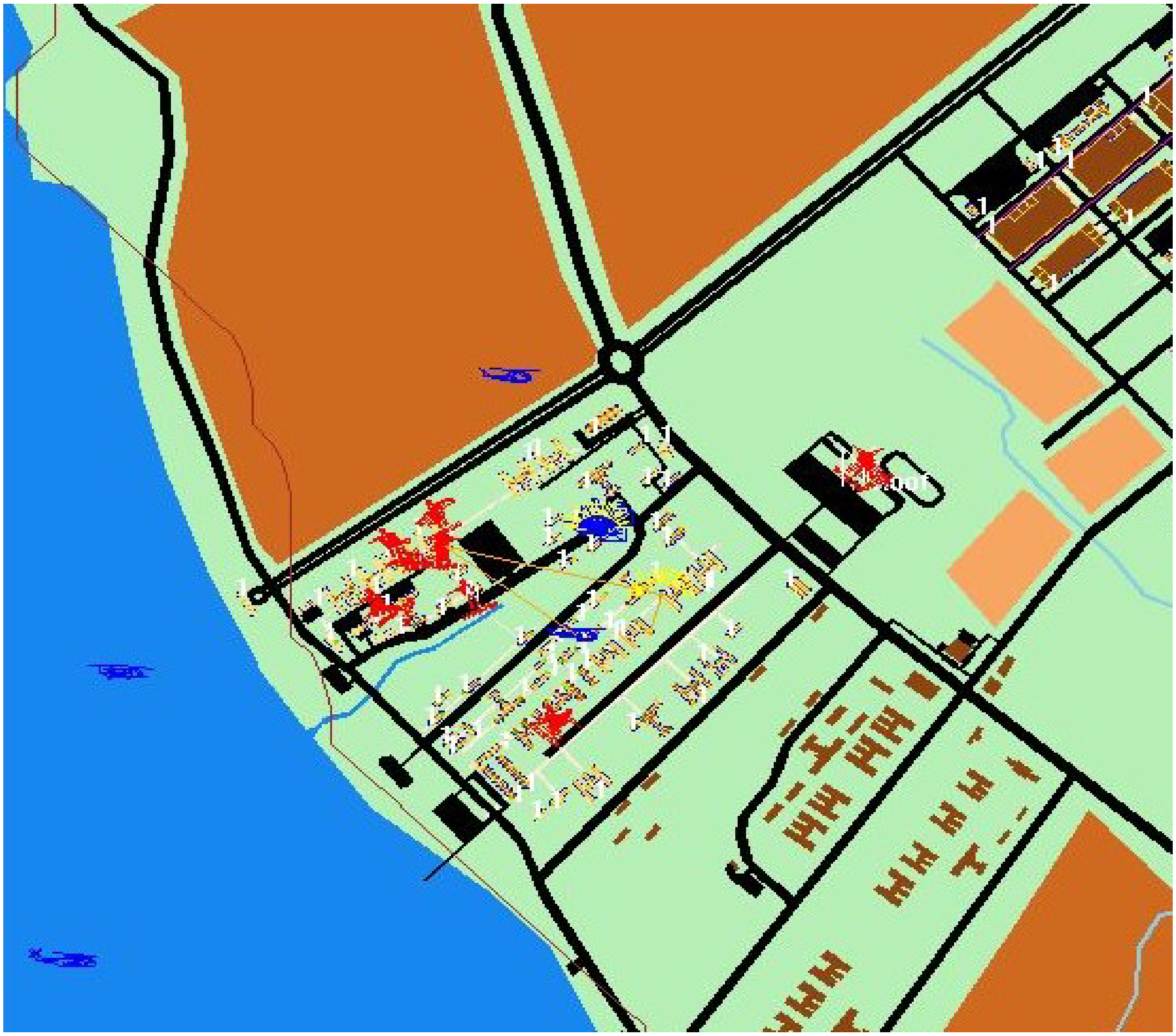
APPENDIX E. JCATS SIMULATION DISPLAYS



JCATS 'playbox' view of simulation. Aircraft enroute to objective area.



Objective area view of aircraft approaching LZs.

Aircraft disembarking troops in objective area.

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